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ABSTRACT

This hearin focused on the "Five-Year Outlook for Science and Technology" report. (The original concept called for the submission of a one-time report to be followed by annual updatings. Due in part to transfer of responsibilities to the National Science Foundation-NSF during the years 1976 to 1982, three full-fledged reports were prepared.) The hearing includes: (1) testimony by and/or prepared statements of George Low, Floyd Bloom, James Ling, and Richard Rettig; (2) statement of H. Russell Cort and Elizabeth Cort, principal investigators of an NSF-funded report titled "The Five-Year Outlook on Science and Technology: Views of Users" (which is included in an appendix) and (3) in another appendix, various background materials, including the text of the reports under consideration (the three NSF 5-year outlook reports, three National Academy of Sciences 5-year outlook reports, and the first combined annual science and technology report and outlook), the statutory requirements for the report as mandated by the Science Policy Act of 1976 (Public Law 94-282), costs of the reports, and time and frequency of submission. Questions about the utility, format, and mode of preparation of the outlook, contributions of the National Academy of Science reports, and other topics and issues are explored. (JN)

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OVERSIGHT REVIEW OF THE FIVE-YEAR OUTLOOK REPORT ON SCIENCE AND TECHNOLOGY

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HEARING

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

NINETY-EIGHTH CONGRESS

SECOND SESSION

JANUARY 24, 1984

[No. 129]

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OVERSIGHT REVIEW OF THE FIVE-YEAR OUTLOOK REPORT ON SCIENCE AND TECHNOLOGY

TUESDAY, JANUARY 24, 1984

House of Representatives,
Committee on Science and Technology,
Washington, DC.

The committee met, pursuant to call, at 9:30 a.m., in room 2318, Rayburn House Office Building, Hon. Don Fuqua (chairman of the committee) presiding.

Mr. **Fuqua**. The committee will come to order.

Is the sound system on? The light doesn't come on.

This hearing is devoted to the an important report mandated by the Congress in the Science Policy Act of 1976, the "Five-Year Outlook Report on Science and Technology."

The report was mandated by the legislation which established the Office of Science and Technology Policy, and it was one of several reports aimed at broadening the role which the OSTP would play in the formulation of national science and technology policy and in advising the Congress concerning the Federal Government's role in support research and development.

At the time of the enactment, this committee worked closely with President Ford and his senior staff at the White House. There was some concern, especially in this committee, that the original plan for the establishment of a science office in the White House would be limited to narrow advice on very specific, isolated science questions, a concept which came to be labeled the "job shop" approach. It was our feeling that the role of the OSTP should also include the much broader issues affecting the whole of science, and the longer term policy concerns which affect the continuing health of American science and technology, and the U.S. economy.

We were equally concerned that the committee should be provided with better and more long-range kinds of advice in matters of policy for science and technology. So we wanted to provide a modest incentive to both the OSTP and the Congress to devote some attention to longer term developments.

The original concept for the report called for the submission of a one-time, Five-Year Outlook to be followed by annual updatings. Due, in part, to the transfer of responsibilities to the National Science Foundation during the years 1976 to 1982, we have instead received three full-fledged reports. The first two of these were submitted in May of 1980 and in January of 1982. Both were several volumes and included not only the brief policy statements, but also voluminous statements gathered by the NSF to prepare the report.

One of these statements, in turn, consisted of an extensive report to the NSF by the National Academy of Sciences. In these Academy reports, a committee of scientists gave their considered view on the likely developments in a selected number of fields of science and advanced technology. Those reports by the Academy have constituted a valuable contribution to the preparation of the 5-Year Outlook, although like the reports themselves, they, too, have been quite lengthy. In fact, the third outlook report submitted by the NSF in September 1983 was simply a reprint of the Academy report with little apparent independent contribution by the NSF or any other agency within the administration.

In 1982, President Reagan recommended that the Five-Year Outlook be combined with the Annual Science and Technology Report, and that this new combined report be submitted on January 15 every odd-numbered calendar year. Late last year we received the first of these new combined reports, and it contains a short chapter entitled "Outlook for Selected Fields in Science and Technology." That chapter is very well written, and does, I believe, come much closer to the kind of outlook report which we originally contemplated and which we in the Congress can read and use in our work.

Questions about the utility, format, and mode of preparation of the outlook remain, however, and we expect to explore those questions today. First and foremost is the question of the massive contribution which the Academy of Sciences has made on three separate occasions. We are fortunate today to have with us George Low, Dr. George Low, an old and valued friend of this committee—friend and long-term not in chronological years, George, I might say—who is the current chairman of the Academy's Committee on Science, Engineering and Public Policy. He and Dr. Bloom, the study director for the most recent study, will discuss with us their views on the Academy's contribution.

Another important question is whether the President's Science Adviser, Dr. Keyworth, and his associates in the OSTP are in fact involved directly in the report's preparation so that it reflects the views not only of the scientific community, but also the views and policies of the administration currently in office. And finally we'll get a broader perspective on the questions from several non-governmental witnesses who have special knowledge about the report.

George, let me say it's a pleasure to have you back. While you were in NASA a few years ago, you have been in this room many, many times on varying occasions, and we're again very pleased and happy to welcome you back before the Science and Technology Committee, and we'll be happy to receive your testimony.

Dr. Low. Thank you, Mr. Chairman. It's——

Mr. Fuqua. Pardon me. Mr. Lujan. Pardon me.

Mr. Lujan. I have nothing at this time.

Mr. Fuqua. Thank you.

Thank you, George.

[The biographical sketch of Dr. Low follows:]

BIOGRAPHICAL SKETCH

GEORGE M. LOW
President
Rensselaer Polytechnical Institute

George M. Low was born in Vienna, Austria on June 10, 1926. He came to the United States in 1940, became a naturalized citizen in 1945, and during World War II served in the U.S. Army from 1944 to 1946.

Mr. Low assumed the presidency of Rensselaer Polytechnic Institute in June 1976, following a career in the National Aeronautics and Space Administration (NASA).

A graduate of RPI, Mr. Low received his bachelor's and master's degrees in Aeronautical Engineering in 1948 and 1950. He joined the National Advisory Committee for Aeronautics, NASA's predecessor, as a research scientist in 1949.

At the National Aeronautics and Space Administration, from its founding in 1958, he held assignments in Washington and in Houston. As a key member of NASA's Manned Spaceflight Team, he had responsibility for the Mercury and Gemini Programs, and took charge of the redesign for the Apollo spacecraft following the Apollo fire. He directed the Apollo Spacecraft Program at the time of the first lunar landing.

In December 1969, he was appointed by the President as Deputy Administrator of NASA and guided NASA's transition in the post-Apollo period. In 1970-71, he served as NASA's Acting Administrator, leading the negotiations with the Soviet Union that resulted in cooperation on space projects, most notably the Apollo-Soyuz spaceflight in July 1975.

As part of his professional activities, he is on the Board of Directors of the General Electric Company; a member of the National Academy of Engineering; an Honorary Fellow in the American Institute of Aeronautics and Astronautics; a Trustee of the Committee for Economic Development and the Hartford Graduate Center; a member of the American Council on Education's National Commission on Higher Education Issues; Chairman of the National Academy of Sciences/National Academy of Engineering/Institute of Medicine's Committee on Science, Engineering and Public Policy (COSEPUP); and Vice President of the Association of Colleges and Universities of the State of New York (ACUSNY).

He has received numerous special honors and awards, which include, for example: the Arthur S. Flemming Award (Ten Outstanding Young Men in Government) in 1963; two NASA Distinguished Service Medals in 1969, and one in September 1981 for his contributions to the Space Shuttle Program; the Robert H. Goddard Memorial Trophy in 1973; the Rockefeller Public Service Award in December 1974; and the National Academy of Engineering's Founders Medal in 1978.

He has received the following honorary degrees: Doctor of Engineering, Rensselaer Polytechnic Institute, 1969; Doctor of Science, University of Florida, 1969; Doctor of Engineering, Lehigh University, 1979; and Doctor of Law, Hartwick College, 1981; and Doctor of Humane Letters, Villanova University, 1982.

Mr. Low served as Chairman of the National Research Council's "Committee of FAA Airworthiness Certification Procedures," which completed its work in June of 1980, and he was leader for then President-Elect Reagan's NASA Transition Team, which completed its assignment in January 1981.

October 1982

STATEMENT OF DR. GEORGE M. LOW, CHAIRMAN, COMMITTEE ON SCIENCE, ENGINEERING AND PUBLIC POLICY, NATIONAL ACADEMY OF SCIENCES, AND PRESIDENT, RENSSELAER POLYTECHNIC INSTITUTE, TROY, NY

Dr. Low. It's a real pleasure to be back, Mr. Chairman, especially in this room where really so much was done to build the foundations for the space program that we now have.

Mr. Chairman, members of the committee, I'm delighted to discuss with this committee the Five-Year Outlook Reports, which the committee was instrumental in initiating.

I would like to first review the recent history of these reports from the standpoint of the committee which I chair, the Committee on Science, Engineering, and Public Policy, a joint committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. This committee, or COSEPUP as we call it, now has the institutional responsibility for aiding the National Science Foundation in preparing the outlook reports.

Next, I would like to briefly describe our plans for preparing the next—the fourth outlook, and I will conclude with a series of questions that COSEPUP has raised. I will not pretend to answer these questions, but I hope that they form a useful agenda for this committee to consider.

The Academy complex has now prepared three outlook reports for the National Science Foundation: The first in 1979; the second in 1981; and the most recent in 1982. I have copies of these with me and, together, they represent quite a set of volumes, quite a bookshelf.

The reports differ in their contents, however. One strong recurring theme comes through in all of the reports: The enormous vigor and excellence of American science and technology. The reports affirm that we lack neither the ideas nor the talent to remain at the forefront of science and to transform it into public utility through technical innovation.

The three reports together have surveyed computers and communications and plant biology, the science and technology of materials and the next generation of robots, world demography and the world of pure mathematics. They have also surveyed the institutions of science: Graduate education, for example; or the comparative strengths and weaknesses of different national resource systems; industrial research; and the dynamics by which clinical medicine adapts and applies basic biological research.

This is, of course, a very cursory outline. And, therefore, I am delighted that Dr. Floyd Bloom, who chaired the last outlook report, is here to tell you considerably more of this process and procedures and content for that report. Incidentally, the tables of contents for all three reports are attached to my prepared statement.

I should emphasize that the Academy complex—that is, the Academy of Sciences, the Academy of Engineering and the Institute of Medicine—welcomed the opportunity to prepare the outlooks. We were given a rare opportunity to do intensive, yet selective, surveys of the State and future directions for what we believe to be extremely fertile fields in science and technology. In short, our involvement with these outlooks enabled us to give to the Congress a validated view of the state of science and technology—selective, to be sure, but quite indicative of how well we were doing.

Mr. Chairman, with your permission, I'd like to skip over the next couple of pages and enter that, my prepared statement, into the record.

Mr. FUQUA. Yes; without objection, the statement in its entirety will be made part of the record.

Dr. LOW. And continue with page 3 of my prepared statement.

With this background, the primary audience, of course, is the Congress. However, the Academy complex, including COSEPUP, has always believed that there's an equally important second audience, those interested in the progress and processes of science and technology, particularly as they pertain to other societal spheres.

For that reason, we have always encouraged commercial publication of the report to ensure a much wider distribution. We have also encouraged the excerpting of chapters in various periodicals, and have encouraged as many book reviews as would obtain for these reports. By and large, the reviews for the first and third were quite favorable, less so for the second, the latter being criticized in good part for its bulk, a criticism that I might add was also voiced by the Congress.

Next, let me briefly outline our preliminary plans for the fourth volume, which the Foundation has informally asked us to prepare. These plans will be reviewed by COSEPUP after we have the benefit of your views as a result of today's hearings.

In brief, we hope to use as a model the introduction that Floyd Bloom wrote for the third report under the title of "Science, Technology, and the National Agenda." That introduction did two things: One, it summarized, in terms of implications, the chapters in the report; and two, it extracted some overarching considerations for national policy and for the present and future congressional agenda.

An informal survey by COSEPUP of the congressional staff indicated that, of those who found the outlooks useful, the introduction to the report was the most valuable section and something to be emulated in future reports.

If I might digress for a moment, Mr. Chairman, the second outlook I talked about was about this thick, and that is the one that generally did not receive good reviews.

Our last volume was this thick, much thinner, but the introduction, published separately in a summary form, was about so thick, and there's a major difference then in the readability, if you will, by busy people of these three separate volumes.

So our purpose would be to essentially use something next time that is much more akin to the introduction of the last report. We would combine that with the fact that COSEPUP is already engaged in surveying particular fields of science and technology, through research briefings prepared for the President's science adviser and done at the behest of OSTP. These led us to conclude that the fourth outlook should be short, no longer than 20 or 30 pages, and should be based on the research briefings and upon additional material.

That new mode would accomplish several things. It would considerably reduce the amount of time that COSEPUP must spend on the reports, and it would amplify the efforts put into the research briefings. The upshot would be that we would not plan for the fourth volume, to prepare the special selected chapters in selected fields of science and technology, but rather present a much shorter document based on available materials.

Now let me turn to some concerns that trouble COSEPUP, and trouble this committee, too, we understand, as well as other committees of both this House and the Senate.

First, and most basic, is whether the report is indeed useful to the Congress. What is the evidence for that, if any? Is an alternative approach or format desirable? If so, what would it be? Specifically, is the shorter volume—that is, using the introduction to the third volume as a model—welcome to the Congress? Or should the outlook effort be abandoned altogether as a feckless exercise?

Beyond that immediate question, one is inevitably led to a root issue. Is long-term future thinking about science and technology, a purpose that is embedded in the outlook exercise, a vital activity to the activities of the Congress? How does such a role fit into the usual congressional processes? If there is indeed such a role for the outlooks, how might they be reshaped to be more effective in fulfilling that role?

Should, for example, the report be more problem or more discipline oriented? That is, should it try to focus on various new directions in science and technology that are pertinent to a particular national concern, whether environmental, demographic, economic, or whatever, or should it invert that approach, focusing on particular disciplines and then outlining how future directions in that discipline will apply to various national concerns? In short, how can the report provide a better integration of policy with the course of science and technology? What mechanisms might best achieve that?

I fully realize that these are difficult questions, and simply to state the questions does not mean that there are answers. However, given the considerable investment made in these outlooks—not only monetary, but especially in the efforts and finite capacities of first-rate science and technological talent in the United States—these sorts of questions need to be addressed directly and completely.

If I may, I would like to leave you with some comments that Ralph Gomory, the chairman responsible for preparing the Academy's first outlook report, provided to the Senate Subcommittee on Science, Technology and Space in September 1980. Dr. Gomory observed that, and I quote:

> We should pay a lot of attention to an interactive process of improving the Five-Year Outlook now that we have a first pass at it. I really hope that there will be a good deal of dialog, fairly concrete and detailed, about what we have now. And I think that is the way in which you can hope to get really a much better document over the course of time.

I am pleased, Mr. Chairman, that today we have started this dialogue.

This concludes my prepared testimony. I thank you for arranging this hearing. I believe it is both timely and necessary to ensure that the Congress receives the soundest advice on the Nation's scientific and technological enterprise.

I would be happy to respond to questions. But I might suggest, Mr. Chairman, that we first hear from Dr. Bloom, and then two of us could together answer questions.

[The prepared statement of Dr. Low follows:]

PREPARED STATEMENT OF GEORGE LOW, CHAIRMAN, COMMITTEE ON SCIENCE, ENGINEERING AND PUBLIC POLICY, NATIONAL ACADEMY OF SCIENCES, NATIONAL ACADEMY OF ENGINEERING, INSTITUTE OF MEDICINE

I am delighted to discuss with this Committee the five-year outlook reports, which it was so instrumental in initiating. I would like to first review the recent history of these reports, from the standpoint of the Committee that I chair -- The Committee on Science, Engineering and Public Policy, a joint committee of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. This Committee, or COSEPUP, now has the institutional responsibility for aiding the National Science Foundation in preparing the outlook reports. Then I would like to briefly describe our plans for preparing the fourth outlook. I will conclude with a series of questions that COSEPUP has raised. I will not pretend to answer these questions; but I hope that they form a useful agenda for this Committee to consider.

The Academy complex has now prepared three outlook reports for the National Science Foundation: in 1979, in 1981, and the most recent in 1982. The reports differ in their contents; however, one strong recurring theme comes through all the reports: the enormous vigor and excellence of American science and technology. The reports affirm that we lack neither ideas nor talent to remain at the forefront of science and to transform it into public utility through technological innovation. The three reports have surveyed computers and communications and plant biology; the science and technology of materials and the next generation of robots; world demography and the world of pure mathematics. They have also surveyed the institutions of science: graduate education; comparative strengths and weaknesses of different national research systems; industrial research; and the dynamics by which clinical medicine adapts and applies basic biological research. This is, necessarily, a very cursory outline, and therefore I am delighted that Floyd Bloom, who chaired the last outlook report, prepared in 1982, is here to tell you considerably more of the process and content for that report. (The tables of contents for the three reports prepared by the Academy complex are attached.)

I should emphasize that the Academy complex -- that is, the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine -- welcomed the opportunity to prepare the outlooks. We were given a rare opportunity to do intensive, if selective, surveys of the state and future directions for what we believe to be extremely fertile fields of science and technology. In short, our involvement with the outlooks enabled us to give to the Congress a validated view of the state of science and technology -- selective, but quite indicative of how well we were doing.

I should very briefly discuss some administrative aspects to preparing the three reports, since they are important to understanding the role of the Academy complex. The first two outlook reports -- those issued in 1979 and 1981 -- were administered by the executive office of the National Academy of Sciences. All chapters in those two reports were given a peer review, and the entire report was given a final review, and approval, by the Governing Board of the National Research Council. The Committee on Science, Engineering, and Public Policy (COSEPUP) was given responsibility for preparing and reviewing the third report, which we delivered to the Foundation in November 1982. It was commercially published in April 1983, under the title Frontiers in Science and Technology.

The chairmen for the three reports were, respectively: Ralph Gomory, Director of Research and Vice President for IBM; Fred Seitz, former President of the National Academy of Sciences and of Rockefeller University; and Floyd Bloom, then Director of the Arthur V. Davis Center for Behavioral Neurobiology at the Salk Institute.

Let me now briefly review the legislative history for these outlook reports. I apologize if I tell you something you already know; however, I believe that the legislative context is important to framing the concerns that I wish to lay before you. The outlook reports came into being through the "National Science and Technology Policy, Organization, and Priorities Act of 1976." The stated purpose was "to identify and describe situations and conditions which warrant special attention within the next five years to which American science and technology can contribute." The Act gave responsibility of preparing this report to the Office of Science and Technology Policy (OSTP). However, a subsequent reorganization of the executive office of the President in 1977 transferred the responsibility for preparing the outlooks to the National Science Foundation. In 1978, the Foundation, by prior legislative agreement, asked the National Academy of Sciences to assist in preparing the outlooks. That procedural framework remained in place until December 1982, when the "Congressional Reports Elimination Act" collapsed into one, the two separate reporting requirements of the 1976 Act -- an annual report in science technology and the outlooks.

The responsibility for preparing the combined report was returned to the Office of Science and Technology Policy. However, the Act states that the report was to be prepared "with the cooperation of the Director of the National Science Foundation, with appropriate assistance from other Federal departments and agencies as the office or the Director of the National Science Foundation deems necessary." The outlook portion of that combined report was, in essence, defined in the 1982 Act as it had been in the original 1976 Act, and I will not repeat that here. The deadline for preparing these reports was put somewhat ambiguously: "no later than January 15 of each odd-numbered year."

With this background, the primary audience, of course, is the Congress. However, the Academy complex -- including COSEPUP -- has always believed that there is an equally important second audience -- those interested in the progress of science and technology, particularly as it pertains to other societal spheres. For that reason, we have always encouraged commercial publication of the report, to ensure a much wider distribution. We have also encouraged the excerpting of chapters in various periodicals and as many book reviews as we could obtain for the reports. By and large, reviews for the first and third were quite favorable, less so for the second, the latter being criticized in good part for its bulk, a criticism that, as you know, was also voiced in the Congress.

Next, let me briefly outline our preliminary plans for he fourth volume, which the Foundation has informally asked us to prepare. These plans will be reviewed again by COSEPUP after we have the benefit of your views as a result of today's hearing. In brief, we hope to use as a model the introduction that Floyd Bloom wrote for the third report, under the title of "Science, Technology, and a National Agenda." That introduction did two things: one, it summarized, in terms of implications, the chapters in the report; and, two, it extracted some overarching considerations for national policy and the present and future Congressional agenda. An informal survey by COSEPUP of Congressional staff indicated that, of those who found the outlooks useful, the introduction to the report was the most valuable section and something to be emulated in future reports. Combining that with the fact that COSEPUP is already engaged in surveying particular fields of science and technology -- through the Research Briefings, done at the behest of the OSTP -- led us to conclude that the fourth outlook should be short, no longer than 20 to 30 pages, and should be based on the research briefings and upon ancillary materials.

That mode accomplishes several things: it considerably reduces the amount of time that COSEPUP must spend on the reports, and it amplifies the efforts put into the Research Briefings. The upshot is that we do not plan, for the fourth volume, to prepare chapters on selected fields but rather to present a much shorter document based on available materials.

Now, let me turn to some concerns that trouble COSEPUP, and this Committee, as well as other committees of both this House and of the Senate.

First, and most basic, is whether the report is indeed useful to the Congress. What is the evidence for that, if any? Is an alternative approach or format desirable? If so, what would it be? Specifically, is the shorter volume -- that is, using the introduction to the third outlook as a model -- welcome to the Congress? Or, should the outlook effort be abandoned altogether as a feckless exercise.

Beyond that immediate question, one is inevitably led to a root issue: Is long-term future thinking about science and technology, a purpose embedded in the Outlook exercise, vital to the activities of the Congress? How does such a role fit into the usual Congressional processes? If there is indeed such a role for the outlooks, how might they be reshaped to be more effective in fulfilling that role? Should, for example, the report be more problem or more discipline-oriented? That is, should it try to focus on various new directions in science and technology that are pertinent to a particular national concern, whether environmental, demographic, economic, or whatever; or should it invert that approach, focusing on particular disciplines and then outlining how future directions in that discipline will apply to various national concerns? In short, how can the report provide a better integration of policy with the course of science and technology? What mechanisms might best achieve that?

I fully realize that these are difficult questions, and simply to state questions does not mean that there are answers. However, given the considerable investment made in these outlooks -- not only monetary, but also in the efforts and finite capacities of first-rate science and technological talent in the United States -- these sorts of questions need to be addressed directly and honestly.

If I may, I would like to leave you with some comments that Ralph Gomory, the chairman responsible for preparing the Academies' first outlook report, provided to the Senate Subcommittee on Science, Technology and Space on September 19, 1980. Dr. Gomory observed that "we should pay a lot of attention to an interactive process of improving the 5-year outlook now that we have a first pass at it. I really hope," he said, "that there will be a good deal of dialogue, fairly concrete and detailed, about what we have now. And I think that is the way in which you can hope to get really a much better document over the course of time."

I am pleased that today we have started this dialogue.

Mr. Chairman, this concludes my prepared testimony. Thank you for arranging this hearing. I believe it is both timely and necessary to ensuring that the Congress receives the soundest advice on the nation's scientific and technological enterprise. I would be most happy to respond to any questions that you and the other members of this Committee may have.

Thank you.

Attachments
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ATTACHMENT

Frontiers in Science and Technology

A SELECTED OUTLOOK

A Report by the
Committee on Science, Engineering, and Public Policy
of the
National Academy of Sciences
National Academy of Engineering
Institute of Medicine

W. H. FREEMAN AND COMPANY
New York/San Francisco

This report was prepared at the request of the National Science Foundation, under contract No. PRM-8206308.

Note: The National Academy of Sciences was established in 1863 by an Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology for the general welfare. The terms of its charter require the National Academy of Sciences to advise the federal government upon request within its fields of competence. Under this corporate charter, the National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively.

The Committee on Science, Engineering, and Public Policy is a joint committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. It includes members of the councils of all three bodies.

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ATTACHMENT

Outlook for Science and Technology

THE NEXT FIVE YEARS

A Report of the
National Research Council

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W. H. FREEMAN AND COMPANY
SAN FRANCISCO

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A FIVE-YEAR OUTLOOK

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Mr. **Fuqua**. I think that's a very appropriate suggestion. And, Dr. Bloom, we'll be pleased to receive your report and, without objection, the prepared statement will be part of the record. If you wish to summarize or otherwise reduce the report, it would be fine.

[The biographical sketch of Dr. Bloom follows:]

CURRICULUM VITAE

Name: Floyd E. Bloom

Date and Place of Birth: October 8, 1936; Minneapolis, Minnesota

Citizenship: United States

Marital Status: Two children; Married Jody P. Corey

Education: 1956 - A.B., cum laude, Southern Methodist University, Dallas, Texas

1960 - M.D., cum laude, Washington Univ. Sch. Med., St. Louis, Missouri.

Professional Training:

Dec. 1983
*October 1975- /: Director, Arthur V. Davis Center for Behavioral Neurobiology, The Salk Institute, San Diego, California.

July, 1973 to Oct., 1975: Acting Director, Division of Special Mental Health Research Programs, NIMH, St. Elizabeths Hospital, Washington, D.C.

July, 1969 to Oct., 1975: Chief, Laboratory of Neuropharmacology, Division of Special Mental Health Research Programs, NIMH, St. Elizabeths Hospital, Washington, D.C.

Aug., 1968 to July, 1969: Acting Chief, Lab. of Neuropharmacology, Division of Special Mental Health Research Programs, NIMH, St. Elizabeths Hospital, Washington, D.C.

July, 1968 to Oct., 1975: Chief, Section on Cytochemical Pharmacology, Lab. Neuropharmacology, Division of Special Mental Health Research Programs, NIMH, St. Elizabeths Hospital, Washington, D.C.

July, 1964 to July, 1968: Yale Univ. Sch. Med; USPHS Special Post-doctoral Fellow in Anatomy, 1964-1966; Assistant Professor Anatomy (Pharmacology), 1966; Assistant Professor Pharmacology (Anatomy), 1967; Associate Professor Pharmacology, 1968; Research Career Development Awardee, NINDB, 1966-1968; Faculty Advisor to Biological Sciences Training Program, Dept. Psychiatry, Connecticut Mental Health Center, 1966-1968.
July, 1962 to July, 1964: Research Associate, NIMH at St. Elizabeths Hospital, Clinical Neuropharmacology Research Center; Associate in Physiology, George Washington Med. Sch., Washington, D.C.

July, 1960 to June, 1962: Intern and First Year Assistant Resident, Ward Medical Service, Barnes Hospital, St. Louis, and Assistant in Medicine, Washington Univ. Sch. Med.

*Dec. 1983 to present: Director and Member, Division of Preclinical Neuroscience and Endocrinology, Scripps Clinic and Research Institute, La Jolla, California.

Fall, 1959: Assistant Instructor, Dept. Pharmacology, Washington Univ. Sch. Med.

Military Service: USPHS - 1962-1964, Surgeon (Lt. Cmdr.)

Societies: Phi Beta Kappa, Alpha Omega Alpha, Sigma Xi, New York Academy of Science, American Society for Cell Biology, American Association of Anatomists, American Society for Pharmacology and Experimental Therapeutics, American College of Neuropsychopharmacology, Society for Neuroscience, Secretary 1973-1975, President 1976-1977, Psychiatry Research Society, International Society for Stereology, American Physiological Society.

Honors and Awards:

A. E. Bennett Award, 1971
A. Cressy Morrison Award, 1971
Arthur S. Flemming Award, 1972
Mathilde Solowey Award, 1973
Biological Sciences Award, 1974
Washington Academy of Arts and Sciences
Member, National Academy of Sciences, 1977
Member, National Advisory Mental Health Council, 1976-1980
Member, Research Work Group, President's Commission on Mental Health, 1977
Adjunct Professor, Department of Neurosciences, University of California, San Diego, 1977
Member, Alan T. Waterman Award Committee, NSF, 1978-1980
Member, Richard Lounsbery Award Jury, NAS, 1979-81
Chairman, Neurobiology Section, NAS, 1979-83
Distinguished Alumnus Award, Washington University, 1980
National Assoc. of Mental Health McAplin Award Recipient, 1980
Member, National Commission on Alcoholism and Other Alcohol-Related

STATEMENT OF FLOYD E. BLOOM, M.D., STUDY CHAIRMAN, THIRD FIVE-YEAR OUTLOOK REPORT, COMMITTEE ON SCIENCE, ENGINEERING AND PUBLIC POLICY, NATIONAL ACADEMY OF SCIENCFS, NATIONAL ACADEMY OF ENGINEERING, AND INSTITUTE OF MEDICINE, AND DIRECTOR, DAVIS CENTER FOR BEHAVIORAL NEUROBIOLOGY, THE SALK INSTITUTE, SAN DIEGO, CA

Dr. Bloom. Thank you, Mr. Chairman and members of the committee. It's a pleasure for me, as study group chairman, to appear before you.

I'd like to summarize my prepared testimony and speak to three points. Point 1 would be the intent of the report and the process by which we try to achieve it. Point 2 would be dealing with the content of the report. And point 3 would be dealing with some of the implications that we tried to draw from the scientific material that we presented.

With regard to the intent of our report, it was, given the perspective of the comprehensive first two volumes, to try to prepare something that might be considerably more useful to the limited time of the readership and that would speak directly to the needs which Congress articulated in the legislation which led to the "Five-Year Outlook Reports."

Our objective was to prepare a report focusing on a selected array of scientific and technical topics which would be considerably shorter than the previous volumes and which could bring to congressional attention the overriding implications of the scientific and technical developments which we believe to be germane to the congressional agenda, both currently and in the future.

The advantage of working through the COSEPUP, the Committee on Science, Engineering, and Public Policy, is that it represents a very broad spectrum of American scientific expertise, and also contains scholars who are well seasoned in the political process, both having been in Congress and serving in the executive branch. And their knowledge and experience was extremely helpful in helping us distill the scientific content into usable implications.

The process by which the report was prepared was as follows. The topics for the report were selected after an extensive canvassing of the members of all three institutions of the Academy complex, the National Academy of Sciences, the Institute of Medicine, and the National Academy of Engineering. At the end, the final decision for topics was made by the COSEPUP.

Once the topic had been selected, it was then important to reach leading figures who could provide a sophisticated and deep interpretation of their fields so that we would have an accurate scientific reporting of the current status of this science.

Following the preparation of the initial reports by the scientists, a very vigorous and editorial rewriting process was accomplished to be sure that the scientific messages would come through. Our goal was to simplify the science without being simplistic and to retain, wherever possible, the complex richness of the field on which the scientific judgments were based.

Finally, after the reports were edited, they were sent for peer review, and between three and seven expert scientists in each of the fields were asked to comment upon the scientific quality and content. Those comments were then furnished back to the original authors and to the COSEPUP, and a series of meetings were held by which they attained a secure view of peer acceptance of the scientific content of the reports so that they were both comprehensive and had some consensus value in the community of scientists at large.

The COSEPUP itself worked extensively on distilling the controversial views so that we could retain areas of open controversy and indicate areas of interesting and open ferment in the scientific arena.

Now let me briefly summarize the contents of the report, trying again to be simple without being simplistic, and hope that you will have time at some point to read the chapters or perhaps the summaries of the chapters.

The eight chapters essentially boil down to two large areas of science. Four chapters deal with biology, the life sciences; and four chapters deal with the physical sciences and technology.

The biology chapters have a common message. Biological science today is making enormous progress on many frontiers. This leads us to newer and deeper research questions, to wide-ranging theories, and to many important new applications, not only better drugs to treat diseases, but to more productive agriculture, to a better understanding of diseases like cancer and diabetes, and eventually the promise of understanding more clearly the basis of our own mental capacities.

The second half of the report, dealing with the physical sciences and technology, also has a similar comprehensive view. It allows us to see the way in which fields as diverse as surface science, turbulence and fluids, lasers and the next generation of robotics, actually emerge and work together. The preparation from surface science techniques of new transistors and solid-state devices allowed the completion of the computerized instruments necessary to power the computers, to understand the nature of turbulence as it affects life around us, and to help synthesize new lasers. Lasers, in turn, are very important for a wide diversity of fields, from communication sciences to engineering, and even back again to the biological field of health.

As Dr. Low said, the report indicates that science and technology in the United States today enjoys a very dynamic and strong position. And again, to quote our report, if we assume that there will be real growth in research support, the United States can expect to remain at the forefront of virtually all scientific frontiers in the 1980's and beyond.

That's perhaps our most important conclusion. But there are others that I would like to draw to your attention briefly in hopes that we might discuss them if it's of interest.

One such theme is the fact that this is an era of biology. Science in the past has perhaps meant physical science, chemistry, physics, nuclear. The last decade has been one of amazing understanding and advances in the way in which the genes that control our very existences express themselves and create the individual cells of our body and allow them to work together in a functional way.

This kind of insight into the nature of the living body provides us an avenue to get at diseases and disease entities that were previously incomprehensible. We now have direct and fundamental approaches to such issues as heart disease, to cancer, to arthritis, to many metabolic diseases, some of which can be inherited. And the field has moved rapidly. Even in the several months since the report was completed, there have been important new advances in these biological eras.

For example, in the recombinant DNA technology, as well call it—human engineering, cell engineering—it's been possible to work out information that allows us insight into the dread disease Huntington's disease and to understand the nature of the particular gene defect which is transmitted and which puts us very close to having a test which can be used in utero to diagnose which children of a potential carrier of Huntington's disease might in fact come down with the disease.

The second major subtheme I'd like to call to your attention is the relationship between science and technology. We see that very rapidly the scientific discoveries lead not only to important applications, but to whole new health industries. Again, speaking of recombinant DNA, we see that, directly from the scientific bench level, we come up with diagnostic tests which can be used in everyday medicine to help clarify important antigens on the surface of cells to help clarify who can receive what kind of transplant, to determine who carries what particular type of disease entity. We see the combination of surface chemistry leading to new large-scale integrated circuits which make new computers which can generate the information necessary to reach complicated decisions on a whole host of complicated issues.

In fact, the combination of instrumentation and communication is one that we think deserves considerable examination in the future. Most of us still rely on pieces of paper to communicate with each other or face-to-face communication of this kind. That's sometimes very intensive, but it's also very slow, and there are large amounts of information that we simply must bypass because we don't have the time to digest it. It's possible to apply existing technology in the communication sciences to help us all accomplish a better grasp of information that surrounds us.

It's important to call attention to the changing relationship of science and technology. I've spoken to this briefly and won't mention it again. But the fact that, immediately from the scientific level of discovery, one creates not just new ideas and new tests, but whole new industries that 10 years ago had no scientific basis at all. It's a very encouraging sign for the contribution of science to the economic picture.

One could call attention to lasers. Having developed the laser as an interesting tool, it's now usable both in communication over long distances for rapid engineering technologies, but perhaps provides the most exciting new approach to human surgery, to provide virtually bloodless surgery on delicate portions of the body like the retina and the brain, which previously were difficult to operate upon, and now become almost office procedures to use a laser device.

Last, I call attention to the fact that the traditional disciplinary boundaries between the major branches of science, between biology and physics, between physics and chemistry, between the technologies and the fundamental sciences, are really dissolving. Depending upon one's perspective, one might find one's self working on engineering and actually being involved with a biological application, or achieving some insight in biology which helps design a better robot to achieve some of the purposes that human beings would like to relinquish to machines.

These are simply brief examples, and a more rich display of these entities is available in our statement.

We've selected eight leading edges of science and technologies for this third report. And perhaps what gives them some force is that they emerge from a very deep and careful examination of particular fields, each giving a very fertile and dynamic area some detailed credence for your examination. They're by no means all of the important areas, and future "Five-Year Outlook Reports" could indeed explore them in a similar fashion if the Congress has found these useful.

They also provide a basis for extracting the overarching implications from the sciences going on in a way that we believe is important for informing Congress of the agenda which faces them and the Nation in the future.

Mr. Chairman, that's the conclusion of my prepared remarks and my excerpts from them. And with Dr. Low, I am very pleased to have had the opportunity to appear before you and describe these aspects of the report, and would be happy to answer any questions that you might care to address to us.

[The prepared statement of Dr. Bloom follows:]

PREPARED STATEMENT OF FLOYD E. BLOOM, CHAIRMAN, THIRD FIVE-YEAR OUTLOOK ON SCIENCE AND TECHNOLOGY, COMMITTEE ON SCIENCE, ENGINEERING AND PUBLIC POLICY, NATIONAL ACADEMY OF SCIENCES, NATIONAL ACADEMY OF ENGINEERING, INSTITUTE OF MEDICINE

Mr. Chairman, I am delighted to appear before this committee to discuss the Third Five Year Outlook report on Science and Technology, prepared by the Committee on Science, Technology and Public Policy (COSEPUP). As the chairman of that Committee, Dr. George Low has already told you, I was study chairman for this report, which was ultimately published under the title of Frontiers of Science and Technology. I would like to describe briefly the process for preparing the report, some of the contents of the full Report, and several conclusions which were drawn from the Report, specifically to speak to the needs Congress articulated in the legislation which led to this series of Five Year Outlook Reports. My purpose is to provide a further base for this committee in appraising the utility of the outlook reports, and formats for future ones.

When we set out to prepare the third outlook, we were quite aware that the two previous volumes were quite lengthy in their effort to attain a broad coverage of science and technology, and the Committee was concerned that such purposes may not have led to the most effective descriptions for the use of the Congress. Therefore, our objective was to prepare a report focussing on a selected array of scientific and technical topics which was considerably shorter than the previous volume. Furthermore, we sought explicitly to bring to Congressional attention the overriding implications of these scientific and technical developments which we believed to be germane to the Congressional agenda, current and future.

In seeking these objectives, we had the considerable advantage that COSEPUP was the sponsoring committee. That committee, as you may know, represents not only a very broad spectrum of the science and technology community, but also includes people well seasoned in the political process, both in the Congress and in the executive branch. That range of knowledge and experience was fully applied to shaping the third outlook report.

The topics for the report were selected through an extensive canvassing of the members of COSEPUP and all three institutions of the Academy complex -- the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The final selection of topics was made by COSEPUP and me. Once topics were chosen, leading figures in each field were needed to write the actual chapters. Rather than employ science writers to prepare the chapters based on interviews with the scientific and technical experts, we opted to ask experts in chosen fields to write the chapters for the Report, in order that their sophisticated and deep interpretation of recent progress in their own fields would be directly available in the Report.

Next, a very vigorous editorial and rewriting process was followed to assure that the detailed information in the individual chapters would be comprehensible to a much wider readership. While the goal was to simplify as much as possible, certain limits were inherent in the subject matter such as the pure mathematics necessary for accurate description of a complex field such as turbulence. Thus, the goal was achieved through a compromise balancing the need to simplify and the equally critical need to retain the depth and precision provided by our author experts.

Finally, a very extensive and rigorous review process was applied to the individual chapters and to the report as a whole. Each chapter was given a peer review, by three to seven experts in the field. The author was then asked to respond to the criticisms before the report as a whole was reviewed by the entire Committee on Science, Technology and Public Policy. COSEPUP met, in fact, for almost two full days to discuss the report. Those comments by the Committee were also returned to the individual authors for subsequent revision. Thus, we were at the end convinced that the reports of these selected fields were both authoritative, broadly reflective of the concerned scientific communities, and accurate.

Let me now briefly describe the contents of the report before developing some of the conclusions derived from the collective report.

Overall, the report contains analyses of eight areas of inquiry that have had and promised to have important societal impacts, and which reflect the diversity, interdependence, and excitement of contemporary science and technology.

Chapter one is entitled "The Genetic Program of Complex Organisms." It points out that the recent progress in understanding how genes act, not only in bacteria and viruses, but also in plants and animals, including us, harbors both fundamental and commercial promise. For example, we have new insights into the fundamental aspects of cancer; that is, we are learning that rearrangements in the structure of the genetic material, DNA, may be a common element to diverse causes of tumors, including chemical carcinogens and viruses. One consequence is to support a further shift in emphasis from cure to the prevention of cancer. Further, the new knowledge in animal genetics will yield imaginative solutions to other long-standing problems. New and better drugs and vaccines will be manufactured; new and improved plants may be developed and the traits of existing plants enhanced; and the diagnosis of diseases will be improved and new treatments of some of these diseases emplaced.

Chapter two is on "The Molecular and Genetic Technology of Plants." This chapter points out that the understanding of plant genetics has seriously lagged that of animal genetics. Nevertheless, rapid progress is now being made, progress that will be translatable into breeding more useful agricultural plants. Basically, the chapter argues that our capacity for finding faster and less expensive ways to breed crops suited to changing in demand and conditions will enlarge through a fundamental understanding of how plant genes act.

Chapter three is on "Receptors for Hormones and Neural Transmitters." The behavior of cells is modulated by chemical signals -- hormones and neural transmitters. Those signals are transduced by special molecules on the surfaces of cells, called receptors. We have in the last decade made enormous progress in understanding what these receptors do, how they work, and what their structure is. That work, in turn, has led to rapid and highly specific methods for following the responses to drugs of healthy and diseased cells. We have been able to develop better techniques for treating human breast cancers. We have a much more detailed knowledge of how insulin works. In the next several years, we can expect to enlarge considerably our understanding of how a given hormone and neural transmitter actually exerts its effects at the molecular level. The outfall will be improved design of drugs, leading to a new generation of drugs which are much more specific in their actions.

Chapter four is on "Psychobiology." The fields discussed by this chapter are engaged in a boggling enterprise: attempting to understand how the various processes of the brain -- chemical, electrical, biological -- enable us to act and think. This is a field of which I can speak with some greater experience, since it is the field in which my own work has been done. Again, enormous progress is being made by blending both advances in a variety of fields, especially in fundamental biology and in chemistry, with new, often highly expensive tools and instruments. The breadth of the field's subject matter is mirrored in the consequences. For example, we have had substantial progress in understanding some forms of deafness. Studies of brain development will help us to improve the education of children and will help them to reach their full capacities. Studies clarifying the causes of some forms of brain damage will aid us immeasurably in treating brain disorders and neurological damage.

These chapters then constitute the biological section of the report. Their message is a common one: biological sciences are making enormous progress on many frontiers, leading to new and much deeper research questions, to wide ranging theories, and to new applications -- from better drugs to enhanced understanding of major diseases such as cancer and diabetes to the promise of better understanding of our own mental capacities.

The second half of the report is devoted to the physical sciences and to technology, with the topics covered including surface science, turbulence, lasers, and the next generations of robots.

Chapter five is on "Surface Science and its Application." What is remarkable about this field is that it lay fallow until about ten to fifteen years ago when several investigators, especially those at Bell Laboratories, turned their attention to it, using new tools and instruments which had become available in the interim. In that short time, their fundamental work has already led to enormous commercial results and promise. We have an entirely new range of catalysts for the chemical and petroleum refining industries. We have new entries to controlling the expensive and enormous problem of corrosion. We better understand the causes of embrittlement and structural failures. And we have created a new technique for building semiconductors layer-by-layer, called molecular beam epitaxy.

Chapter six is called "Turbulence and Fluids." Turbulence is disordered fluid flow, and its study applies to virtually all moving fluids -- air, blood, water, oil flowing in pipelines, the surface crust of drifting continents or galaxies. The ability to predict turbulence, its course, and its effects are still highly limited, thereby limiting our ability to generically design structures which must deal with turbulent fluids. These structures include turbines, pumps, compressors, aircraft, chemical reactors and mixers, and much more.

Chapter seven is on "Lasers." When lasers were first invented, few people had any insight into what they might actually be useful for. No one need worry about application today; lasers now are vital to an incredible range of technologies from engineering, communication, oinstrument development and human surgery. However, what is most impressive is not what they have done but what their promise is. The chapter focuses on that. In the next several years, we can confidently expect that both new lasers and enhanced designs for existing ones will expand our capacity to use them in communication, in medicine, in ever finer and more precise measurements, and in understanding events at the molecular level, such as photosynthesis or vision.

Chapter eight, the final chapter, focuses on "The Next Generation of Robots." This chapter makes the point that while the current generation of robots can do incredible things, it is still limited by, in part, a lack of basic knowledge. Given fundamental advances and the application, we can expect see a new generation of robots that will enable quicker, more precise communication between people and robots. We can also expect new sensors that will enable robots to see, to feel, to walk, and recognize commands. We can expect robot systems that integrate these traits, leading in time to a new generation that can deal with disorder, one that is able, for example, to pick a specific piece out of a bin of jumbled parts.

Mr. Chairman, I hope this brief survey of the Third Five Year Outlook Report will provide some beginning impression of the complete contents. The recurring theme of the Report reinforces what Dr. George Low said in his prepared testimony: science and technology in the United States presently enjoys a very dynamic and strong position. Indeed, the report concludes that "assuming real growth in research support, the United States can expect to remain at the forefront of virtually all scientific frontiers in the 1980s and beyond."

Beyond that very basic and important conclusion, the report came to several others which I would like very briefly to present to this committee. One such subtheme, with very large utilitarian implications, is that this is indeed the era of biology; that is, we are witnessing a virtual explosion of biological knowledge in an enormous range of fields. The direct implication is that in the next several years wholly new techniques will emerge for dealing with the chronic diseases which are now major causes of the deaths and the incapacitation of Americans — heart diseases, cancers, arthritis and related disorders, metabolic diseases, and so forth. The techniques that will emerge out of fundamental insights in biology will not be simply palliative but will penetrate to the fundamental causes of these diseases. Quoting from the report, "these techniques will be highly specific, quite complex, and will require fundamental understanding for effective application."

A second major subtheme of the report is that of the changing relationships of science and technology, with consequent implications for how we convert new technology to utilitarian purposes. For one, the report concludes that the pace of technological innovation is quickening. We see evidence for that in lasers, in the very rapid application of recombinant DNA methods, in the emergence of a whole new series of catalysts out of surface studies, and in the development of very large integrated circuitry out of a congeries of work done in several fields of solid state science. The point is that, as the report notes, "in such an era of rapid transformation, the structures for basic research and technological development must be dynamic and must be constantly freshened by the infusion of new and highly trained scientists and engineers, by the very best instrumentation, and by unfettered communication of fundamental knowledge."

With regard to the interplay between instrumentation and communication of knowledge, the Report calls attention to an apparent paradox: while American scientists and engineers continue to be at the frontiers of their fields, the manner in which they exchange information with one another has really changed relatively little. Thus, we still continue to rely to an extraordinary extent upon printed paper or meetings for exchanging information on the progress science and technology. Against that, as we all know, there is now an enormous range of new communication devices which can both speed and improve the accuracy of communication. The report argues that the time is propitious for examining more closely the infusion of new communication modalities in research.

The Report also calls attention to the changing relationships of science and technology, the report further notes the much closer coupling of fundamental science with technology. It points out that we are increasingly seeing the emergence of advanced research technologies, in the sense that these are not "just" incremental improvements upon what already exists, but in fact are completely new, created out of basic research.

This is true, for example, in surface science and its creation of molecular beam epitaxy, lasers and a wholly new technology for clinical diagnosis and surgery, in plant biology and the new approaches to breeding unusual seeds, and in computer science and the emergence of much more versatile industrial robots. Related to this is the report's argument that we need to pay considerably more attention to enhancing the symbiosis of science and technology. The issue is mechanisms to catalyze technology transfer: that is, translating basic knowledge won largely in the universities into technological innovation, done in the main in private industry.

Finally, the Report emphasizes that the traditional disciplinary boundaries between the major branches of science and between the sciences and technology are dissolving. For example, quoting from the report, "solid-state physics has merged with material science and with chemical engineering in computer science to produce new catalysts and microelectronic fabrication methods." Further, "optics, solid-state physics, and cellular biology have merged in the creation of flow cytometry for analyzing cellular components." Also, "robotics and psychobiology merge in the analysis of vision." The report points out that the implication of these dissolving boundaries is that "they alter the question of which areas of science should have priority support." While it notes that occasionally particular targets of opportunity may be selected for special attention, the "highest priority is balanced strength and an insistence on the highest quality. We cannot choose selective excellence in science."

This, then, is a very brief summary of the various implications which emerged from our analysis of eight leading edges of science and technology. What gives them force is precisely that: that they emerge from an in-depth and very careful examination of particular fields, each a very fertile and dynamic area. This is, I believe, a major strength of the outlook reports, in that they provide to the Congress not only windows into particular fields but also a basis for extracting, inductively, overarching implications of the sort which must inform the future Congressional agenda.

Mr. Chairman, this concludes my prepared statement. I thank you and the Committee for an opportunity to present my views on the third outlook. I would be most happy to try to respond to any questions which the Members or you may have.

Thank you.

Mr. FUQUA. Thank you very much, Dr. Bloom.

Maybe both of you would comment on this, and it gets back to the demonstrations you made about the size. How do you cover all the vital areas of science and technology, the issues, without having some kind of voluminous report? How do you avoid that? Maybe use less words to say what you intend to say, but will the shorter version cover the essential issues that need to be brought to the attention of the American public, the administration as well as the Congress?

Dr. LOW. Mr. Chairman, I think you have posed the key question, and let me begin to answer. Perhaps Dr. Bloom can help me also.

I have been Chairman of COSEPUP for about 3 years now. And there have come before us all kinds of issues in science, engineering, medicine, and the like. We do, as I mentioned earlier, a volume called "Research Briefings." At least we do these at the present time. There is no indication that we will do those forever. But those briefings, which covered a volume like this, in the past year covered such exciting fields as immunology, solid earth sciences, the use of computers in design and manufacturing, artificial intelligence and chemistry.

We believe that from the outlook we get as the Committee on Science, Engineering, and Public Policy, through doing the briefings to touching on other fields, through additional information, we can then probably draw the general conclusions that we believe could and should be of interest to the Congress, the kind of conclusions that Dr. Bloom talked about in his summary chapter having to do with the state of science, the health of science, the health of technology, general directions.

We think we can do that from the overall effort of a committee like ours, from the research briefings, from other things, without commissioning the independent and separate chapters as we did particular in Outlook No. 2.

Floyd, do you want to comment.

Dr. BLOOM. I can only add to that by saying that the areas that were selected for the "Five-Year Outlook Report, No. 3" were stated to be selected areas, but they were selected with double purposes, one might say. They're both exciting and comprehensive areas of coverage which had not been reported to Congress in detail. But by focusing on them in this particular round, we provide a scientific basis to see how general fields of science emerge into specific fields. By having looked at the genetic program of cells, we're in a very good position to understand the operation of the immune system of our body and the way in which antibodies are constructed.

So, within the biological field, and equally so within the physical sciences field, a general overview provides a basis for an extended detailed coverage for particular topics which will come to Congress' attention in future reports.

Mr. FUQUA. Now, some of the earlier Five-Year Outlooks were developed by the National Science Foundation and, therefore, somewhat reflect the outlook that they perceive, or the focus that they perceive. Whereas science was probably more focused—or was focused on more than technology.

Do you think, under the procedure we're using now, that we have a chance to look at the advantages and disadvantages of both whether an agency responsible for the outlook is giving the broad perspective maybe that it should?

Dr. LOW. I'm not sure, Mr. Chairman, that I'm the proper person to answer that question since, in effect, my committee is the subcontractor, if you will, to prepare the outlook, and we have responded for all three times to the National Science Foundation.

More generally, however, I know that the Foundation and the Office of Science and Technology Policy have expressed a great deal of interest in technology as well as science, that there is a significant shift as I perceive it from not only my committee's vantage point, but also from my current position, in the interest in technology, in engineering, and the applications thereof.

Mr. FUQUA. I guess that it adequately identifies the emerging problems of national significance and that they not be slighted, whether it be science or technology—or not either/or, but that things of most significance have an opportunity, or that they are presented in a fashion so that the decisionmakers and policymakers have benefit of that.

Dr. LOW. Well, as far as the presentation is concerned, I would mention again that the agency that I head in this regard is purposely titled the Committee on Science, Engineering, and Public Policy. It also reports to the Institute of Medicine. It is the only creature of the three academies—the Academy of Sciences, the Academy of Engineering, the Institute of Medicine—it reports directly to the presidents and the councils of those three academies.

We have on our committee people from industry, people from academe, a good representation of, I think, people of the highest quality who are well qualified to view science and technology as a whole. Our input has been made through the National Science Foundation and, through it, to OSTP. And, so far, it has been accepted by those agencies, as near as we can tell.

Mr. FUQUA. Well, now, do you have an opportunity, rather than just submitting a menu of opportunities in the report, but to also label priorities, to issues or areas that you feel deserve greater attention maybe than others?

Mr. Low. I think, Mr. Chairman—well, first of all, the answer is "Yes" to your question. I think that the last, the third Outlook, was really a transitional piece in that context. And in the introductory material that Dr. Bloom prepared, there is a section entitled "Wider Implications."

So, in effect, Dr. Bloom has summarized the eight chapters, then went on to an important section entitled "Wider Implications," having to do with health care issues, having to do with the pace of technological innovation, with improving scientific and technical communication, research-based technologies, coupling science and technology and the boundaries of science and technology.

We think it was our focusing on these issues that presents an important aspect to the Congress of what our committee believed were the important issues relating to the health of science and technology in this particular time period.

Mr. **Fuqua**. Mr. Lujan.

Mr. **Lujan**. Thank you, Mr. Chairman.

Focusing on these issues, that presents an important aspect to the Congress of what our committee believed were the—the important issues relating to the health of science and technology in this particular time period.

You know, I guess one of the things I enjoy about this committee, is it kind of gives us a window into the future and see what is coming along, and of course, that is what the reports are supposed to do.

I'm just wondering, as I looked through the reports, most of it was extension of present knowledge that we have, for example, extending on genetic engineering or what will happen with lasers in the future, or robots. I am interested to know if the committee saw some different things that are on the horizon.

For example, if this report had been made decades ago, we would not have foreseen the effect of the communications industry, the satellites, the robots, the lasers, the genetic engineering, those sorts of things.

Did you spot something way out there that might be something new for us?

Dr. **Bloom**. Congressman, it's a very interesting point, but in actual practice, active scientists are very bad prognosticators and most of the scientific advances that we could extol as having important implications for the future now were really discovered a decade ago. At the time of their original discovery, it wasn't really seen—it wasn't really considered. Knowing that, we can now do this, and it took perhaps mistakes, perhaps good fortune, and perhaps some applied creative effort on the part of many hard-working bench scientists to put, what appeared to be bleak and perhaps mundane discoveries into operation on a momentum that gives us recombinant DNA work.

And so it's very hard to predict. But, for example, one could point today to the idea that by having in hand the actual structure of the surface of a cell that allows it to respond to chemical signals in its environment, we could regulate whole hosts of disease entities which we now can't even understand. Important diseases like schizophrenia, depression, and even alcoholism might be understandable in terms of the surfaces of cells that make them sensitive or resistant to certain signals in their chemical environment.

That requires a whole range of biological knowledge which is almost at our fingertips, but not quite in hand, and certainly not ready to put into practice. If we were writing the 14th 5-year outlook perhaps a decade from now, I have some confidence—not total security, but some confidence, that many of those issues will be actually practicing ideas.

Mr. LUJAN. Why is not the DOD part of this whole study? If there's anyone that spends billions of dollars in research—although primarily technology—I guess also in the life sciences—why are they not in here? They seem—to me, anyway—to be the ones most involved, if you measure it in terms of dollars spent. Was that an oversight?

Dr. LOW. Mr. Lujan, that is really part of the question that the Congress, I believe, must answer. The Congress has asked initially the National Science Foundation, and the Office of Science and Technology Policy—to prepare an outlook like this, with the National Science Foundation and whatever agencies of Government they would seek to get into the act, if you will. They, in turn, asked us to prepare this one section of that report which has become the volume—I might State, however, that those of us——

Mr. LUJAN. They prepared, you say, this section of the report. Who do you mean by "they"?

Dr. LOW. We, the Committee on Science, and Engineering, and Public Policy of the academies prepared this report. It was subsequently included in some report that either the National Science Foundation or the Office of Science and Technology Policy presented to the Congress. It may have been appended completely or it may have been included in summary.

So they, in this case, the National Science Foundation, contracted with the Academy complex to prepare the Five-Year Outlook Report. We, in turn, the Academy complex, through my committee, selected the chapters, got the people involved.

Many of the scientists and engineers involved in the preparation, of course, are also familiar with and work on Department of Defense activities, so there is a cross-fertilization through the committee and through the individual scientists, but to my knowledge, the Department of Defense is not asked to contribute directly.

Mr. LUJAN. So what you're saying, there probably is indirect input by those people that are in both camps.

Dr. LOW. Yes, sir, certainly in advanced fields.

Mr. LUJAN. Thank you.

Mr. FUQUA. Mr. Walker.

Mr. WALKER. Thank you, Mr. Chairman. Mr. Chairman, I will say one thing for this morning's hearing, and that is that the "solar doghouse" that I once made infamous in this committee has now found an occupant, the COSEPUP. [Laughter.]

The—the report—from just a summary I've seen here this morning—does not seem to include very much in the way of space initiatives, talking about our goals in outer space.

I guess my first question is, given the fact that we appear as though we are going to have to devote large sums of money if we are to follow the administration's request for the next several years from this committee toward space, would that be included in your real growth criteria that you're giving us for the need to—to advance science overall?

Dr. **Bloom**. Let Dr. Low speak about applications to science research, but in fact, sir, the chapters do speak directly to space, although they don't spell out that as a particular implication. For example, the creation of new solid-state devices to allow for the construction of larger computer devices is certainly important in calculating the orientation and navigation of the spacecraft.

The issues of surface science allow us to prepare better heat shields for interaction between the space capsule and known or unknown environments. The calculations of turbulence, for example, and turbulence is an important field, are certainly important in navigation re-entry and trajectory of the spacecraft.

Agricultural advances by the geneticists might be capable of being applied as a space program for specific types of agricultural research that are not possible within our own atmosphere. Those are just a few and so although we didn't explicitly comment on applications in space, I think they are relatively easily derived from the scientific topics that are currently covered in this report.

Mr. **Walker**. Well, my question was somewhat more mundane than that. You said in your statement, Dr. Bloom, or quoted from the report indicating that if we have real growth in scientific research over the next several years, that we can maintain a lead in virtually all aspects of science and, therefore, hopefully in the products of science later on.

Now, my question is, if we are putting money into a space station, into other space applications, if we're putting money into the kinds of things that Mr. Lujan was mentioning, DOD research, that adds up to a part of real growth in science and research. Is that the kind of real growth that is reflected, then, in that statement?

Does—would you include that as a part of the money that would reflect a real growth, a scenario for the nation?

Dr. **Bloom**. Actually, sir, I would not. I would say that in order to maintain the type of growth we're talking about, we're talking about infusing continuously young scientists, the training of new minds for the application at the fundamental level, to provide the discoveries that your colleague was asking about that will make the discoveries and important applications of the 1990's and the next century. The growth of the field is a growth from the base up, although, as I have tried to also indicate, technological discoveries help feed fundamental discoveries, but in essence, our growth is a growth from the bottom.

Mr. **Walker**. Well——

Dr. Low. Mr. Walker, if I might add and argue a little bit with my colleague here, I have viewed the space program in part as a tool of science and a tool for doing science. Certainly with the kinds of things that we've done in the past, with the kinds of things that are planned to do in the future, we will see out further; we will learn a great deal about all of the fields of science, and in that sense, the space program, whatever it is, whether it's the unmanned probes or perhaps a future space station, is, I believe, a highly valued tool for doing exploratory science.

What we're doing in these outlook reports is looking at a much more fundamental level, what are the reaches of science, rather than how should it be conducted.

Mr. **Walker**. Well, I'm trying to get some perspective on what we are going to be asked to do in terms of authorizing money at some point in the future. Now, you see, if we are also authorizing money for a space station, we're authorizing money for things of that kind, we can show a very substantial growth in the amounts of money that this committee has committed to science over the next several years, and yet, if I understand your definition, those very substantial increases may not, in fact, give us the real growth criteria that you think is necessary for the advancement of science.

That gives me a problem because it becomes, then, a very tough budgetary and political problem for this committee to deal with and for the Congress to deal with.

Dr. **Low**. And my answer to that, Mr. Walker, would be that parts of what you would be appropriating—authorizing for the space program—clearly is an area of space science, and it would form that underlying base that Dr. Bloom and I have been talking about.

Other parts of the program are clearly in the advancement of engineering and technology and they should not be measured toward this particular basic scientific growth, but only in terms of providing the tools to carry it out.

Mr. **Walker**. Thank you, Mr. Chairman.

Mr. **Brown** [presiding]. Thank you, Mr. Walker.

Gentlemen, I'm next up in terms of questioning, even though as chairman, I wouldn't normally do that, but I will in this particular case.

Following up very briefly with what Mr. Walker said, I think what you've been trying to do is to distinguish between the expansion of basic knowledge, which basically comes from creative minds, new scientists and so forth, the development of sophisticated tools for the use of those scientists, and then a third matter which both of you referred to in your statements, the application of that knowledge for the social benefit of mankind, which is the development of technology.

And part of our problem seems to stem from the fact that we lump all of these together and sometimes get them out of balance because we lump them in one fashion or another. Is that statement reflect your views in the matter?

Dr. **Bloom**. Wholeheartedly. I wish you'd been on our committee when we were trying to write that report.

Mr. **Brown**. Yes.

Let me say that I have perused all of the previous reports. I find them to be of great value. I look at them in perhaps a somewhat broader perspective and I'm going to make another statement and ask you to comment on it.

The title of your pamphlet, "Frontiers in Science and Technology," is one which allows the scientific community to interact in some fashion to look at the whole spectrum of our posture in science and technology.

The Congress, in its needs, frequently has a much narrower agenda, one in which it is more concerned with some immediate problem, maybe it is national defense, maybe it is budget allocation. It needs some imput, but rarely in the case of Congress does it feel a high motivation to review the full scope of science and technology and consider where we're going.

On the other hand, there are instruments of the national government, and there are instruments of the national society that benefit from that. The Office of Science and Technology Policy ought to be looking at that. The Office of Technology Assessment ought to be looking at that.

A number of other persons involved in the analysis of science need that and our educators in public policy around the country need that, as well as a large number of other kinds of groups.

Now, this is almost exactly the problem that confronts OTA, in how to take a broad subject, looking at the future as to impacts of a technology and distilling it into a fashion that a particular congressional committee can use to make policy or pass a certain bill at the present time.

It seems to me that what we need is a process which produces a result which has multiple uses and which can be, as one of those uses, focused on the needs of Congress. In some attractive way, some well-packaged way, but overall, we need to look at a broader picture from this.

Am I making a statement that you would generally agree with in this respect?

Dr. Low. Yes, Mr. Brown, I tried to address that subject, also, in answer to a previous question. I think we're beginning to focus on such a process. At least we would recommend to you that we are doing so in the transition from this very thick volume earlier to the thin volume and its summary, and perhaps a process where we could use the membership of my committee, the Committee on Science Engineering, and Public Policy, to synthesize for the Congress, through this committee, what some of the emerging issues are as a result of reviewing a much larger scope of things.

Mr. Brown. Well, I appreciate this. This committee, incidentally, has a much broader perspective on science and technology than most of the other committees of Congress and tends to appreciate the breadth of work. But you're going to find, I think, future criticism that you're producing a huge volume of work, unnecessarily large, to the needs of the Congress or a particular Member of Congress, which is true, looked at in a narrow perspective, but looked at in a broad perspective, all of this material contributes to better public policy in the science and technology field.

Let me ask one additional question which is on the minds of the committee and many of its members right now. You have indicated a focus on the connections between science and technology and we maintain a distinction between them, why, the connection becomes very important. The Academy itself is seeking to build better connections between the science, the engineering, the health, the Research Council and so on.

Is it possible that the structure of the Federal Government is not adopting as well as the Academy is to the needs of bridging this connection between science and technology in the public policies that we're adopting at the present time?

Dr. Low. Mr. Chairman, you're asking me a question that is somewhat beyond my knowledge since I've been away from Washington so long, but let me try to comment anyway.

I have seen, through my position as chairman of this Committee on Science and Technology and Public Policy, Science Engineering and Public Policy, a great change in recent history, in recent times, recent months or perhaps years. Both the National Science Foundation, under its present leadership and the Office of Science and Technology Policy under its current leadership is exhibiting an enormous interest in the growth of technology, the use of computers, for example, in design and engineering, which was one of the major pieces we did for research briefings to Mr. Keyworth.

An enormous interest in engineering education, in engineering research, and I see that because we are getting through the Academies all sorts of questions on this. So I think there's a change that is taking place today within the existing structure of the executive department, and enormous interest, and I think focusing on the technology side of it and putting it together with the science side. So I am very encouraged by that.

Mr. Brown. Well, you're quite correct about that. There are a number of proposals, some of them being made by the administration, as to how to better cope with this problem. But I'm looking at this in the light of the general political debate this year which is taking place as to how we improve the quality of our national economic life; how we more effectively couple our huge resources in basic research with the development of technology and the meeting of social needs, and I think your report puts excellent emphasis on that which we could benefit from in addition to our better understanding of the frontiers of science itself.

I'll recognize Mr. Bateman next.

Mr. Bateman. Thank you, Mr. Chairman.

I've listened to the statements of our distinguished witnesses and have been going through most of the materials that have been furnished and I'm struck by the fact that I see much in the way of the outlines, the subject matters to be dealt with as a part of the—I would take it, some sort of macro-survey of scientific challenges. There seems to be an area of omission that perhaps isn't real. But maybe even due to the fact that I can't correlate the terminology that I'm accustomed to to what I have seen.

In the area of research and physics, I did not see much there. I thought I might even see some investigation of quarks and such. I found no references, nor did I read any exortation that we make progress with new laboratory facilities for the enhancing of our research capability in the area of nuclear physics.

Would you all comment on this. Have I not seen something that's really there or is it that there's a perception that the other things override it in importance and, therefore, it's properly not there?

Dr. Bloom. Congressman Bateman, in Outlook report 2, the silver one—

Mr. Bateman. The silver.

Dr. Bloom. Chapter III under part 1 deals with the structure of matter and deals both with astrophysics, nuclear structure and particle physics in that global overview. And in the scientific briefings prepared by the Academy's special panels for the Office of Science and Technology Planning in the first year, radio astronomy and the need for space laboratory telescopes were dealt with in specific and may constitute part of the fourth Five-Year Outlook Report as currently being envisioned if it's requested.

As we said, the red book deals with selected topics. We tried to provide a balanced view and at the particular time with the people available to us, that particular area was not highlighted, but it was certainly not out of mind at the time the reports were constructed.

Mr. **BATEMAN**. It is in a silver publication that doesn't seem to be among the abundance of others——

Dr. **BLOOM**. We will get it for you, sir——

Mr. **BATEMAN** [continuing]. That I have.

Dr. **BLOOM**. It was the second of the Five-Year Outlook Reports.

Mr. **BATEMAN**. The fact that it is not highlighted in the new summary, which at this point is all that I have seen, does not indicate that it's been put on a back burner or it's not regarded as still of great significance to the scientific community.

Dr. **BLOOM**. Yes, sir, that's correct, it is certainly present in our minds, but not specifically included in this round of coverage.

Mr. **BATEMAN**. Are you comfortable with what appears to be the degree of emphasis in the administration and Congress to fund large, new scientific laboratory facilities that are essential in the area of physics such as the electron accelerator laboratory?

Dr. **BLOOM**. Well, again, it's difficult for a medical biologist to comment effectively on everything, but, in fact, having visited the Fermi accelerator laboratory, I was impressed with the opportunities that derive new particles that might be useful in the treatment of solid cancers and so, as Dr. Low said when speaking of space science, I find it hard to draw the line from one target to where its applications might be in discovering certain fundamental processes of life. We often uncover ways to apply them to other avenues of life. Therefore, a good quality investment in science, I think, is the primary criterion. If it's good science, its applications will broaden.

Dr. **LOW**. If I might add to that, Mr. Bateman, it has really been a long time before the Federal Government has funded significant facilities at our universities, about 15 years, to my knowledge, since there's been a special line item for such a facility, and that becomes today a very critical problem for the health of science and technology in this country, particularly because so much of science, so much of engineering is becoming big science, big engineering, big research, and I think both the administration and the Congress needs to face up to that as an issue in the near-term future.

Mr. **BATEMAN**. As a corollary to what we are discussing, do you see that there's a need for any change in emphasis on the part of the Federal Government to move away from national research laboratories as opposed to, within the finite means available, giving more support to our university-related laboratories?

Mr. **LOW**. Mr. Bateman, I'm really not the expert on that question, and I have read the various reports on the national laboratories. As some of the members of this committee know, I came out of the NASA environment, which has its own laboratories. I think that debate is one that must be focused on, but I would rather not add to it today because I really have not studied it myself.

Mr. **Bateman**. Fine. I thank you both.

Thank you, Mr. Chairman.

Mr. **Brown**. Thank you, Mr. Bateman.

I'd like to just remind the members of the committee first that, in accordance with the policy of the chairman, I'm trying to recognize members in order of their appearance in the committee, and second, that we have several other witnesses and the Chair would not be offended if any member should not take his full 5 minutes. [Laughter.]

The next member is Mr. Lewis.

Mr. **Lewis**. Thank you, Mr. Chairman.

I have—looking through the summary, I do not see any applications to organ transplants or inner space or to the vast areas of computers. I'm just wondering if these are accepted now or why aren't they included with the tremendous interest in these areas.

Dr. **Bloom**. Well, sir, transplantation is really in part a combination of the sciences of immunology, detecting which transplants will be acceptable and why they might be rejected and advances in surgical technology, and in essence, both are covered in generality, dealing with cell-surface receptors and the biological expression of those receptors on cells. In this particular Five-Year Outlook Report, we're laying the base for a future coverage, and again, we might point that one of the OSTP briefings by the National Academy this year was on the science of immunology and its implications do impose on the critical issue of organ transplantation.

As far as computers, they are present in every chapter of each of our outlook reports, from the mathematical computations required to predict turbulent issues, the nonlinear dynamic equations that are there, to the construction of computer-integrated circuits with molecular surface techniques for synthesis of the solid state devices to robotics, the next generation of robotics depending upon advances in both computer science and in biological analysis of how computers might sense and move robots.

So they are, again, not specifically addressed as such, but beneath the surface of many of the chapters lie both of the general bodies of science to which you inquire.

Dr. **Low**. Mr. Lewis, if I might add briefly to that, I had appended to my prepared statement the tables of contents of the three outlook reports, the 1979, the 1981 and the 1982 volumes, and I think they should be considered together.

For example, in the 1979 volume, there was a major chapter on computers and communications. Therefore, we did not feel in 1982 that this warranted a repetition in the current volume. So much of which is not evident in the red book is not there because it had been there in the previous two volumes.

Mr. **Lewis**. I see. How about on inner space, the oceans? Do you consider this under your flow applications or where would a Congressman look in the silver edition or the red edition to find what's happening with the inner space?

Dr. **Low**. I'm not sure that that is a topic that's been covered yet.

Mr. **Lewis**. One other—one final question. The outlook does not apparently show any assigned priorities to the various opportunities. Could you explain why you haven't prioritized in this area?

Dr. BLOOM. The broad coverage of these eight topics is, in a sense, a specifying of priorities of selected opportunities at that particular point in time. At the same time, trying to build a case for a fundamental approach to high-quality science, and trying to predict where a given targeted area might have its outcome is not necessarily a fruitful or accurate way of doing so.

The opportunities—areas of special opportunities—have been highlighted over the last 2 years in a series of 12 topical area reports to the President's science adviser, areas of particular opportunities that might benefit from the application of new resources at the current time. And to some extent, they overlap partially with the list from the third Five-Year Outlook Report, but they considerably extend and expand the format list of individual topics.

Mr. LEWIS. I see. Thank you.

Thank you, Mr. Chairman.

Mr. BROWN. Thank you, Mr. Lewis.

Mr. MacKay.

Mr. MACKAY. Dr. Low and Dr. Bloom this is extraordinarily helpful to me as a new member of this committee. One of the things I've been trying to determine is what questions should this committee be asking. It seems to me that this committee came about perhaps a couple of decades ago through the realization of the same need that this report came about. That is to say, somebody in the Congress needs an over-arching view of where we're headed and what are the policy questions.

It appears to me that somewhere leading up to the 1976 act, someone decided that this committee needed something in addition to help us frame the questions. In your report, or your testimony, Dr. Low, you were talking about the question of how would this be vital to the Congress. The Congress is your primary audience.

There are some questions that, it seems to me, you dealt with by implication, but they are fundamental questions that you do not deal with, and I would like to find out if you think these are appropriate, and if so, whether your agency is in position to answer these questions.

What percentage of the total research dollar is going now into the Defense Department and how that ties in. Mr. Lujan asked this question, why have they not? Do you have the authority to require them to participate? I mean, is there a problem that more than half of the defense—more than half the research dollars in this country going through that or through DOD Defense and yet, as far as I can tell, you did not discuss with them except that some of your people might have been working on their projects.

I am sitting now as the person with the policy responsibility, and it seems to me that it's more than just curious that the people who did the research report to summarize to me and try to show me the policy questions didn't talk to one of the major policy issues, which is, why is more than half the research in America going through the DOD instead of NSF?

Mr. BROWN. Would the gentleman yield to me for a——

Mr. MACKAY. Yes.

Mr. BROWN [continuing]. Briefly? Almost a facetious comment, but both Dr. Low and Dr. Bloom are very wise men and I think they want to continue making these reports, and they know what questions to stay away from and what ones not to stay away from if they're going to keep making these reports.

But you may answer anyway, Dr. Low. [Laughter.]

Dr. Low. Specifically, Mr. MacKay, I don't think that we in the Academy complex have the authority, in preparing this report, to seek Department of Defense participation. I believe, however, the Act states that the National Science Foundation can call upon such agencies of government as it wants to in helping it prepare the report.

Mr. MacKay. Do you think that it would be appropriate, and perhaps in the bigger volumes of the report this information is there, do you think it would be appropriate to sketch a historical background as to where the Federal money has gone and a general consensus, if any, from the scientific community as to whether the Federal participation in basic research and in technology is becoming more useful, more helpful? I mean, that's the policy question we should be asking, and although I think this is fascinating to see how all of the streams of research are merging to form new rivers, that's fascinating and I get to be one of the front-row spectators.

I am supposed to be the guy that's trying to decide to dam rivers or to rechannel things and you're just sort of describing, "Look what happened, folks." You get to know this quicker than anyone else in America.

Is one of the policy issues that the Congress is not able to get information rapidly enough to participate in the process?

Dr. Low. This is the key question, Mr. MacKay, and, as a matter of fact——

Mr. MacKay. That's what I would have thought the 1976 act was driving at. Otherwise, as your question asked, is this vital to Congress?

Dr. Low. It is not, to my knowledge, the question that was posed to us by the National Science Foundation to which we responded. Separately, the Committee on Science, Engineering, and Public Policy is surely mandated by the Academy complex to look at important issues in this country. We debated this past weekend when we had our last meeting whether it is timely, whether it is even possible to ask and get answers to the kinds of questions you are now raising.

Is it possible to draw an economic inference from the science and the technology that's being funded, not only by the Federal Government, by also by industry. It is a question that economists have wrestled with for many, many years. I have not, in the many years that I have looked at it, ever been satisfied that the question has been answered. I would guess this committee has also never really been satisfied.

Mr. MacKay. I'm not even sure this committee's asking the right questions. That's the question I'm asking and what other questions we should be asking.

If we are the trustees of the citizen's interest in this, that is the legislative or congressional branch, we should be helping, we should be setting policy, and I have not found in my brief time here that we've ever addressed that kind of question. I've been wondering when in the congressional cycle we ask those questions.

I think, in the absence of anything else, whether you are wise men or not, today's the day.

Dr. Low. Mr. MacKay, I very strongly relate to the question. Back 8 years ago when I was testifying before this committee as a member of the executive department, for NASA—we had some studies done on the effects of the specific technologies that NASA had developed on the economy as a whole, and it is possible we learned then to do this on a spot basis, if you will.

You can take a specific field and ask an economist to give you a specific answer. We tried to generalize from that. I don't know how successful we were in doing that.

I think it is a terribly important question for the Congress and the executive department to ask. I urge you, however, that in asking it, you get some good discussion going as to how one best addresses it and whether it is possible to do it. It is not easy to get the answers.

I have wrestled with the question for many years and, to my knowledge, nobody has yet been able to come up with definitive answers. Very important, but very difficult questions. It is not the question we addressed, that we were asked to address, in this instance.

Mr. MacKay. The title of your committee is very provacative, "Science, Technology and Public Policy." Do you issue reports where you address that, even though they're not under Government contract?

Dr. Low. Yes, we do. All of our work does get issued. A very critically important report, not critical report, but perhaps the most important report we issued in the last year was one on scientific communication and national security. That is a public document and a very important one today, for example.

Mr. MacKay. Fine.

Mr. Brown. I apologize, the bell didn't go off, Mr. MacKay.

Mr. McCandless is next.

Mr. McCandless. Thank you, Mr. Chairman.

Gentlemen, I, too, am somewhat new on the Hill, but not necessarily new to the governmental process. This is a learning experience for me and I hope you will take it in that context.

I look at the report with the limited time I have and zero in on a specific area of interest to me, Chapter 2 summary, which deals with genetic technology of plants. I come up with cliches like "Nobody knows why," "We may learn," "Increased cooperation will aid in breeding more useful plants," and "Large knowledge increases capacity." It's reminiscent of some of the textbooks that I've read where the generalizations are informative, but not specific and we get back to some of my colleagues' previous questions dealing with "We are a policymaking body where all appropriations of government originate." And it would appear to me that with the limited information that I have here, with all due respect to the very learned people that put this together, that these general statements are not necessarily overall informative for someone to generate something which can be useful and give this particular aspect of your report some specific direction, rather than the shotgun approach. I don't know if you wish to comment on that or not, but these are my observations for whatever value they are.

Dr. BLOOM. Well, I believe, sir, that the comments to which you refer are necessary given the present state of our scientific understanding of genetic expression of plants and our ability to manipulate them. There are certain aspects of certain plants that we understand very well, but we don't yet understand the differences between strains of plants, so it's necessary to say no one really knows the answer to these questions at this point. The need for scientific communication, I think, is to be able to relate chance observations made when pursuing a particular objective, but finding something in a secure way that's meaningful, to apply that knowledge from one area of scientific research on botanical specimens to another area of research.

It's through that kind of cooperative synergism that the advances take place. I regret if it appears to be overly ambiguous, but we felt on balance that this was an important area of scientific understanding to be called to Congress attention and the specific areas in which the research is occurring at the present time are very optimistic for broader application, more important agricultural products in the future.

It tries also to make clear that what we understand about certain plants, being able to clone certain types of plants is not yet at a state of knowledge that can be applied, for example, to cereal plants which would be of enormous benefit, both economically and nutritionally. And so it portrays, I think accurately, the current state of ferment, solid understanding in certain areas, and broad areas in which considerably more must be understood in the future for it to make that science a technology.

Mr. BROWN. Would the gentleman yield to me and I'll ask the chairman to give him another minute?

Mr. MACKAY. Yes.

Mr. BROWN. The gentleman raises an extremely important question which has been before the Agriculture Committee for some period of time now with regard to the proper balance of fundamental research and the agriculture science problem, and one of the policy decisions made in the Department, and reflected in its new 6-year plan for research, was a modest shift from existing fields of research expenditures into more work in plant genetics so as to reflect the emphasis that is here.

This report, from a policy standpoint, will give weight to that recommendation being made in the Department of Agriculture, which is being resisted, as you might expect, in some quarters because it changes things. It changes the distribution of research funds.

Now, this is one of the points that lead me to see the value of this kind of a report, even though it doesn't deal in the specifics that the gentleman quite properly would feel better if it did deal in. It does deal sufficiently with the policy aspects to be very useful, not only to this committee, but to other committees of the Congress in my opinion.

Mr. MACKAY. If I may, Mr. Chairman, one more thought here. We talk here about plants, the genetics of plants and you leave us hanging there. The layman does not understand why, so with the indulgence of my colleagues, it would appear to me, then, that if I were on the Agriculture Committee, I would have a better understanding of why they lag, what might be a policy to implement in order to bring plant life and the genetics related to it up to the animal husbandry aspect of it.

Mr. BROWN. I'll give you one answer. The Department of Agriculture has not been able to quickly transform agricultural scientists who spent 30 years of their life doing one thing into doing something else. The program that the Congress enacted, that of competitive grants to bring in the best researchers into this field, has been underfunded for the past 5 years.

Mr. MACKAY. Thank you, Mr. Chairman. Thank you, gentlemen.

Dr. LOW. Mr. Chairman, if I might just add one brief comment on that. Since the red book was published, we have also done the research briefings, and in the first volume of research briefings there's one on agricultural research, which addresses many of these points more specifically than we were able to do at the time of this book. Mr. Brown, especially, you might want to avail yourself of a copy of this and we will send you one.

Mr. BROWN. Thank you. Mr. McGrath.

Mr. MCGRATH. I have no questions.

Mr. FUQUA. Mr. Reid.

Mr. REID. Mr. Chairman, following up on some of the statements made by other members, I think we all have a concern in that we're on this committee and supposedly setting the policy for this country in various fields. We are, in effect, as Congressman MacKay has said, not doing that, but coming in, and you're giving us a firsthand report on what's already happened.

Looking at your statement, Dr. Bloom, I'm interested more specifically in a couple of things that you've said. For example, your testimony was that there's new insights into fundamental aspects of cancer. One consequence is to support a further shift in emphasis from cure to prevention of cancer.

Now, if you don't know, perhaps you could direct my attention to the appropriate party. From your standpoint, is there more that Congress could do to consolidate, make more specific, the work that's going on in the country relating to cancer?

Dr. BLOOM. I think that's a very active field, sir, and that Congress has done substantially to support that field over the past decade. It's the product of that intense effort of support that Congress has provided to the molecular genetics field through the effort to understand the nature of cancer and its treatment that has brought us to the level of understanding we're at at the moment.

Mr. REID. You are satisfied, then, with the approach that Congress is now using through a number of different funding programs.

Dr. BLOOM. I would say in specific response to that comment that the evaluation of the judgments of the field as supported by the Director of the National Cancer Institute take into consideration these broad advances in the scientific discipline, but many times we're surprised at contributions to this understanding that might come from the study of yeast or the study of maize that help us understand what it is that cancer really consists of and how it's initiated, how it comes to survive and how it comes not to be embattled by the natural body processes. But I would say, sir, in general, Congress has substantially supported this field and we would hope that that continued interest and effort might be maintained.

Mr. REID. But the criticism that the press has in this regard—and I'd appreciate your comment to this—is that there is no program. As you say, there is funding all over a wide spectrum and some of it contributes quite accidentally to some progress that's been made, and maybe there should be a focal point on a research program for cancer.

Dr. BLOOM. Well, sir—just to restate a couple of the points we hoped to have made, we believe there are times when opportunities arise that deserve specialized intensified effort, but that in general, if we go for the highest quality of research across that broad spectrum, we are far more likely to uncover those surprises that will contribute in an unexpected way to the more rapid progress and understanding of the situation.

So we do have in place a very targeted program on cancer, which is the program waged by the National Cancer Institute, but in addition to that, studies at the level of normal cell biology, normal cellular genetics, even plant genetics, contribute substantially to our understanding of the way in which cells express their genetic capacity and in which genes present in all of our cells all of the time can be triggered to create the situation that we now call cancer.

And so I would say that we have both situations currently in our present base of scientific support mechanisms, and both appear before various arms of Congress at various times for their support.

Mr. REID. One last question. The first bill that we worked on last year was the Emergency Math and Science bill, and we had a long line of witnesses who basically told us that our teachers in science, or students interested in science, were at one of the lowest levels ever for a number of reasons.

Now, would either or both of you gentlemen comment on that. Do you think that we do have in the United States a shortage of scientists and a shortage of equipment to assist scientists in their endeavors?

Dr. LOW. Mr. Reid, I didn't fully follow your question. Are you talking about the university level or are you talking about the high school level?

Mr. REID. Any level.

Dr. LOW. I can speak best at the university level, and I can speak best about engineering, and not science. Yes, there is a shortage of engineering faculty. That shortage is one that has been with us for some time and it is still not healing itself, and, yes, there is a shortage of equipment at our universities. Instrumentation equipment, both for doing science and for doing engineering.

The elementary/secondary level question is a very different one. I am not as close to it as I am to the university level, but I think there is a serious issue also about the teaching of math and science at the elementary/secondary level in our schools.

Dr. BLOOM. Let me add that the stream that turns out the teachers is the same as the river that furnishes the advances in science. It is based upon having in the laboratories up-to-date equipment in order to do the best progressive research with current state of the art techniques, and lacking that ability to fund from our current research base the newest instrumentation, we cut off one arm of the possible flow of new information that will provide the material by which to educate the teachers who will encourage our children to go into these scientific disciplines. So we've constrained that flow of development at many points along its origin to its completion.

Mr. Reid. Thank you, Mr. Chairman.

Mr. Fuqua. Thank you, Mr. Reid.

Mr. Mineta.

Mr. Mineta. Thank you very much, Mr. Chairman.

Dr. Low and Dr. Bloom, I really would like to thank you and all the others who have been involved in—in this process of preparing the Five-Year Outlook. Let me ask, in sort of reviewing the Five-Year Outlook format and the reports, we don't really deal with those portions where maybe projects which have been overrated continue to get their financial support, and we don't say, "Hey, we ought to take a look at those and continue the support for those projects."

Should we have a section in this report dealing with—maybe pinpointing some of those that are maybe overrated, not to be getting less support?

Dr. Low. Realistically, Mr. Mineta, that would be a very difficult question to ask of a committee of scientists and engineers such as we are, who are volunteers in this effort of putting the report together. I think it is a question that should be asked of the agencies of Government, and I think the agencies of Government could ask us specific questions about a given field. But to ask a group of volunteers who are university people or people from industry to really come to grips with that question, I think it is not in the nature of human beings to be able to do that.

Mr. Mineta. Well, let me ask, since we do rely on the National Academy of Science and bring all this talent to focus on the needs, to crystal ball where we might be going, we are able to bring the advantages of the scientific community to really look at all of these things and yet the reputation of the Academy as an institution is that it is science oriented.

Now, does that present a conflict of interest or an appearance of a conflict?

Dr. Low. First of all, Mr. Mineta, this particular report is done by a group within the Academy complex that involves the Academy of Sciences, the Academy of Engineering and the Institute of Medicine. Clearly, all of us who belong to the academies, I would say almost all of us who belong to the academies, have one thing in common. We believe that basic science and its applications represent a terribly important contribution to the health of the Nation, and to this, we plead guilty.

Beyond that, I think we will take an objective point of view about what are the fields of the future that should be focused upon. In all honesty, I think we would have created difficulty or perhaps take a less objective point of view or be less able to focus on saying this particular field of science has run its course.

I think a manager, the director and administrator have to answer those questions. A group of volunteers on the committee always has had great difficulty answering that. When I was in

NASA, again, we sought the advice of our committee structure on directions we should go. We took it upon ourselves as administrators to decide what we should not do.

Mr. **Mineta**. Well, the thing is that as lay—at least in my instance, I'm a lay person who is not technically oriented, and yet we're making decisions and voting on policy issues, as has been pointed out by my colleagues, and the question is, how do we use to the Nation's best advantage, and our trying to determine public policy, this tremendous kind of resource that we have in all of you, because of your own expertise in your specific areas, and how do we take those resources, that human value that we have, and the time that you're expending as volunteers on this—on the preparation of this outlook, and turn that to our best advantage as a country in a world where we're competing with others who are doing it with subsidies or whatever it is that they're doing? The lack of restraints of antitrust law, whatever it might be.

We're trying to compete in that world economy and how do we make sure that we're getting the best from all of you as we try to exercise our public policy responsibilities?

Dr. **Low**. I think you're getting it, Mr. Mineta, in the positive sense, getting it, for example, in the research briefings that we talked about before that have also been published and are available as to the fertile directions, and to take a nonscientific direction, but an engineering direction, we have in this most recent research briefing a chapter on the use of computers in design and manufacturing.

We think that's a terribly important field to help make the country productive again. And specifically, we recommend in it that there are two things that are needed: one is more engineers with a practical bent, engineers who are willing to do hands-on work, who understand the problems with industry; and second, the underlying scientific foundation, the classical research foundation that lies beneath the fields such as computer-aided design, computer-aided manufacturing and so on.

That is the kind of advice that we we can provide, that is seriously given, in which we involve the best experts in the country to provide. When it comes to the converse of the question, what should we no longer do, I truly believe, and I may be—this is George Low speaking, and not the academy speaking—I truly believe that it is very difficult for a committee structure, any committee structure such as the one I head, to really be able to develop consensus in that. There are just too many people who are afraid to step on other people's toes, and we all face that.

Therefore, I think the paid people in the Government, in the National Science Foundation, in the Office of Science and Technology Policy, as they do everyday, ought to be the ones that are called upon to say, "What shall we stop, what is no longer fertile, what should we no longer do."

The inference is there, in a little bit of that, in our reports in the fields we don't cover, but I don't want to put too much—place too much stock in even that, because we may have left something out that is still very important.

Mr. MINETA. Well, I want to thank all of you for the tremendous contributions that you have made in helping us trying to come to these conclusions on public policy.

Thank you, Mr. Chairman.

Mr. FUQUA. Thank you, Mr. Mineta.

Mr. Walgren.

Mr. WALGREN. Thank you, Mr. Chairman.

Thinking along that same line, I can certainly understand that there are toes that are stepped on when we say we shouldn't do this, but the other side of that problem is whether or not we're picking up things that we aren't doing that deserve support, and as you indicate, Dr. Low, you say that the report does attempt to point out fields of the future that should be focused on.

In your view, are we picking up areas where we are not doing some things? Is there guidance in the report sufficient to assure broader policymaking bodies that certain areas that really do have potential that may not be appreciated in the very present are, in fact, encouraged and pointed out as areas not of overrated areas of overrated, but areas that may be being underrated, for which we will pay a penalty if we don't add strength in those areas?

Dr. LOW. Mr. Walgren, I think that the chapter in the summary entitled "Wider Implications" does exactly that. It points out those areas in summary form that transcend all of the specific areas of research. For example, there's a section entitled "Improving Scientific and Technical Communication." We learned by doing the third Outlook that there are possibilities now of helping all of us do science through the modern communication techniques. These techniques are not yet being applied universally in what is being done.

There is a void there that we pointed out, for example. There may be other areas as well.

Mr. WALGREN. Was there discussion in the development of the report of what I gathered to be one of the thrusts the last several years within the National Science Foundation which was a turning away from the social sciences and adding strength to the physical sciences? In your development of the report, was there discussion of the potential of the social sciences as opposed to those that are addressed as I see here?

Dr. BLOOM. Yes, in the original grand design for the third Five-Year Outlook Report, two topics that touch on social science-related issues, one of economics and one of child development, were broached, and we were unable to provide satisfactory chapters that survived peer approval, and so for the present time, they have not been battled out and compromised to the point where we could give a consensus, comprehensive and accurate statement of the opportunities and problems within those areas. They are still under consideration and might be subjects for future Five-Year Outlook Reports, but they certainly were present in our minds in trying to plan the areas that should be highlighted for congressional approval.

Mr. WALGREN. I guess what I am asking is that this report seems to take some selected areas and give you a little view of each. That's a relatively easy or noncontroversial approach to giving a Five-Year Outlook that is designed to give the Congress the power to make judgments because we would want to do all of these.

Is it the role of the Five-Year Outlook to go beyond simply saying these are the interesting areas to point out areas of deficiency?

Dr. BLOOM. I can only answer that in part by repeating an earlier answer, that in selecting these—selecting them both for their content importance as perceivable today, but for their broader implications as scientific enterprises that contribute not only to their own understanding, but spread out and overlap other technological and scientific areas.

Mr. WALGREN. But you did not deal with the question, really, of deficiency in certain areas.

Dr. BLOOM. We did not specifically look to target on areas where we might be doing more than we have beyond the implications that we could draw from.

Mr. WALGREN. All right, then, let me ask the general question: We have had—and your organizations and yourselves have been heavily involved in three reports now, as I understand it. What would you like these reports to do better? What would you like to see in them that might, from an overall social perspective, enable them to be more useful?

Dr. LOW. Mr. Walgren, my recommendation in my testimony and subsequent questions and answers was that we should consider this last report a transitional one to a new focus, a new mode, where we would take the research briefings that we prepare for the Office of Science and Technology Policy, as well as some other information that we as a committee get, summarize the results in the Five-Year Outlook of important and fast-moving fields of science and engineering, but then do the hard work of concluding from those fields some generalities that we believe should be of interest to Congress.

For example, I mentioned earlier that we had, separately from the outlook, done a report on scientific communication and national security. We are concerned today that that entire issue may have important effects on the health of science and the health of technology in the United States. We might bring that to the Congress as part of the conclusions reached in the outlook report as an area where the Congress should focus.

So, to answer your question, we think that instead of commissioning chapters, as we had done in the previous outlooks in science and technology, we should instead use other information, such as research briefings, to focus on critical issues in science and technology, to condense those and to bring those to the attention of the Congress.

Mr. WALGREN. Thank you.

Dr. Bloom, I assume I could ask you to resume to the same question about what would you like these reports to do better, what?

Dr. BLOOM. Well, sir, the reports are designed for the needs of Congress and to make them better, we would need a rephrasing of what Congress would like us more to do. You've given us a good example. If you tell us that you would like to know about areas of potential deficiency, that's something that could be placed on the agenda at least for consideration, to see if the data base is there for us to tell you what a consensus might say are deficient areas that might be taken up.

If one wanted priorities, although we're not really currently competent to do that, we might at least look for ways in which another way of achieving priorities might be achieved. We are doing this at the request of Congress, hopefully to be useful to Congress. It was Congress that created the legislation that allowed us to prepare it, and so, to make it most useful, if the originators would tell us how they would like it reshaped, I think there'd be sympathy on our part to try to make the product better. We were hoping to do that with this transition.

Mr. **Walgren**. Well, I'm sure that there will be some ideas talked about—some direction that we might be able to give if I don't miss my guess.

Thank you very much, Mr. Chairman.

Mr. **Fuqua**. Thank you very much, Dr. Bloom. We appreciate you being here. George, glad to see you again and have you back and thank you very much for all your efforts on behalf of what I think is a very constructive report and more, I think, in line with what Congress had originally intended. Sometimes it takes a while before the dust settles and we arrive at something that is a very useful document, and I think you have provided that in this latest report and we thank you.

Dr. **Low**. Thank you, Mr. Chairman, we really appreciate this opportunity.

Mr. **Fuqua**. Thank you.

Our next witness is Dr. James Ling, Assistant Director for Institutional Relations, Office of Science and Technology Policy, the Executive Office of the President.

Dr. Ling, we're very pleased to have you with us today.

[The biographical sketch of Dr. Ling follows:]

BIOGRAPHY

JAMES G. LING

Dr. James G. Ling received his B.Chem.E. degree from Cornell University in 1953. He received his M.S. in nuclear engineering from Iowa State in 1959; M.S. in industrial engineering from Stanford in 1966; and Ph.D. in nuclear resource management from Stanford in 1967.

From 1953 to 1954 he was a chemical engineer with the DuPont Company. He entered active duty with the U.S. Air Force in 1954, retiring from the Regular Air Force in 1975 with the rank of Colonel. His military assignments included aircrew duty from 1954-1958; Project Engineer in reactor development at AEC Headquarters from 1959-1963; Systems Analyst in strategic mobility on the Joint Staff from 1967-1970; and Combat Operations Analyst in Vietnam from 1970-1971. He was also Special Assistant for R&D in the Office of Assistant to the Secretary of Defense (Atomic Energy) from 1972-1973; Technical Director of the Defense Energy Task Group in 1973; and Assistant for Plans and Programs in the Directorate for Energy (Office of Secretary of Defense) from 1973-1975. He holds the aircrew rating of Master Navigator and is a graduate of the Air Command and Staff College and the Naval War College.

Following retirement from active duty in 1975, he joined the MITRE Corporation as a Group Leader in the Energy Resources and Environmental Systems Engineering Department. In 1975 he served as a MITRE consultant in the Energy Research and Development Administration's Field and Laboratory Utilization Study. From 1976-1978 he managed a MITRE study team which evaluated the National Science Foundation's Materials Research Laboratory program. He joined the U.S. Department of Energy (DOE) in September 1978 as Director of Program Implementation in the Office of Field Operations Management (Energy Research). In that position he developed procedures for performing management appraisals of DOE's multiprogram laboratories and chaired the teams that conducted appraisals of Argonne National Laboratory, Brookhaven National Laboratory, and Lawrence Berkeley Laboratory. Since November 1981 he has been a Senior Policy Analyst in the Office of Science and Technology Policy, Executive Office of the President.

Dr. Ling's awards include the Legion of Merit with Oak Leaf Cluster and the Joint Service Commendation Medal.

STATEMENT OF DR. JAMES G. LING, ASSISTANT DIRECTOR FOR INSTITUTIONAL RELATIONS, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, EXECUTIVE OFFICE OF THE PRESIDENT

Dr. LING. Chairman Fuqua and members of the committee, I'm pleased to have this opportunity to address the committee on the subject of the Five-Year Outlook Report on Science and Technology. Specifically, I will discuss the usefulness of this report to the Office of Science and Technology Policy and the desirability of continuing the report, either in its present or some other form.

When we consider the Five-Year Outlook Report, three key questions must be asked: What was it intended to accomplish; has it; and could it? Let me take up each of those questions in turn.

The function of the Five-Year Outlook is stated in Public Law 94-282 in fairly general terms. My understanding of the intent is that the report is to provide a mechanism for forcing regular, mid-range, that is, 2 to 5 years hence, policy analyses of national issues and problems related to or arising from science and technology.

These analyses would serve as a basis for subsequent executive branch and congressional attention. The preface to the 1981 report states that it serves as an interagency discussion document and a focus for raising problems that might merit policy consideration in the coming years.

Has the report accomplished its intent? In order to answer that, let me deal with several aspects of the last two reports. The 1981 report was organized by generic policy issues and functional areas. From our perspective, it was not very useful. For one thing, we were collectively quite familiar with the subject matter. That is, we had enough expertise in all the areas covered by the report so that we learned nothing new.

The report occasionally described administration policy that we had developed, and that was not very informative to us. We have been using the President's Annual Science and Technology Report to the Congress as a principal document for articulating policy, so using the Five-Year Outlook for that purpose is redundant.

The 1982 Five-Year Outlook dealt with selected areas of fundamental science and engineering. It provided an interesting survey of those areas, but again, it was not informative to those of us who had expertise in those areas.

We did, however, reorganize and edit the introduction and incorporated it as a chapter of the 1982 Annual Science and Technology Report. We have no evidence that the Five-Year Outlook has forced any high-level reassessment of executive branch plans or actions. Certainly, it has not proved useful as a means of identifying policy issues for the attention of our office.

Could the report accomplish its intent? The answer to that requires an examination of how science and technology policy issues are identified and dealt with in practice.

The language pertaining to the Five-Year Outlook in Public Law 94-282 suggests that science and technology issues are distilled from a systematic analysis of a universe of potential problems. In practice, we find that science and technology policy is not made in isolation from national policy. Scientific or technical content of a science and technology policy issue is only one, frequently subordinate, factor in determining what converts scientific problem into a national issue.

A national science and technology policy issue has to be timely, politically important, and the Government must be a necessary participant. It is very hard for scientists to include these factors in their analyses, particularly a year or more in advance of publication.

Thus, we find that the Five-Year Outlook in its current form lags, rather than leads, the issue identification and resolution process. I think the timelag is further increased by the process of reviewing and producing such a report.

The review process also results in a product that is more bland than the original. By the time there is a reasonable consensus on an issue in the scientific or technical community and a report is published, the problem is probably already being worked on.

What, then, are some alternatives? Timely identification of science and technology issues will always have to be done in a dynamic environment on a continuing basis. Our office is in constant contact with the science and technology community, as well as Government agencies and Congress. As you know, important issues are discussed among these groups whenever necessary, and not on the basis of an annual report.

The Office of Science and Technology Policy also recognizes the need for periodic review and assessment of issues, but we do it annually as an intensive staff activity, rather than rely on an externally produced document. That way, the information we use is current, and we are able to focus on the multiple facets of each issue and explore them to whatever depth seems warranted.

One activity which we have found useful in the past year and a half has been the presentation of topical briefings by the National Academy of Sciences through the President's Science Advisor, Dr. George A. Keyworth. These briefings were presented in the fall of 1982 and also in the fall of 1983.

In all, 12 briefings have been presented and the briefing papers have been published in two reports by the National Academy. The briefings were prepared in response to a request from Dr. Keyworth. Topics were selected by our office from a list recommended by the National Academy.

The specific charge to each topical panel was to critically assess its field and to identify those research areas within the field that were likely to return the highest scientific dividends.

The topical briefings have several features which make them useful. They are prepared and presented by experts in their fields. They are timely. They are usually focused and concise and the briefing approach allows for interaction and discussion.

These features need to be kept in mind when considering the potential value of issue-oriented studies. While the briefings are aimed at near term funding priorities, the briefing papers have far more overall impact than the type of material covered in the 1982 Five-Year Outlook.

In summary, the Five-Year Outlook Report, in its present form, is good for surveying science and technology problems. It has not demonstrated that it can fulfill its original intent, that is, to identify science and technology issues for policy consideration. If it is to be read at the policymaking level, it needs to say something new, authoritative, useful and say it briefly.

This concludes my formal presentation and I would be pleased to answer any questions from the committee.

[The prepared statement of Dr. Ling follows:]

TESTIMONY OF DR. JAMES G. LING
ASSISTANT DIRECTOR FOR INSTITUTIONAL RELATIONS,
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
EXECUTIVE OFFICE OF THE PRESIDENT

TO THE COMMITTEE ON SCIENCE AND TECHNOLOGY
UNITED STATES HOUSE OF REPRESENTATIVES

JANUARY 24, 1984

HEARING ON THE "FIVE YEAR OUTLOOK" REPORT

CHAIRMAN FUQUA AND MEMBERS OF THE COMMITTEE:
I'M PLEASED TO HAVE THIS OPPORTUNITY TO ADDRESS THE COMMITTEE ON THE SUBJECT OF THE FIVE YEAR OUTLOOK REPORT ON SCIENCE AND TECHNOLOGY. SPECIFICALLY, I WILL DISCUSS THE USEFULNESS OF THIS REPORT TO THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY AND THE DESIRABILITY OF CONTINUING THE REPORT EITHER IN ITS PRESENT OR SOME OTHER FORM.

WHEN WE CONSIDER THE FIVE YEAR OUTLOOK REPORT, THREE KEY QUESTIONS MUST BE ASKED:

WHAT WAS IT INTENDED TO ACCOMPLISH?
HAS IT?
COULD IT?

LET ME TAKE UP EACH OF THOSE QUESTIONS IN TURN.

THE FUNCTION OF THE FIVE YEAR OUTLOOK IS STATED IN PUBLIC LAW 94-282 IN FAIRLY GENERAL TERMS. MY UNDERSTANDING OF THE INTENT IS THAT THE REPORT IS TO PROVIDE A MECHANISM FOR FORCING REGULAR, MID-RANGE (THAT IS, TWO TO FIVE YEARS HENCE) POLICY ANALYSES

OF NATIONAL ISSUES AND PROBLEMS RELATED TO, OR ARISING FROM, SCIENCE AND TECHNOLOGY. THESE ANALYSES WOULD SERVE AS A BASIS FOR SUBSEQUENT EXECUTIVE BRANCH AND CONGRESSIONAL "SPECIAL ATTENTION." THE PREFACE TO THE 1981 REPORT STATES: IT SERVES AS AN INTERAGENCY DISCUSSION DOCUMENT AND A FOCUS FOR RAISING PROBLEMS THAT MIGHT MERIT POLICY CONSIDERATION IN THE COMING YEARS.

HAS THE REPORT ACCOMPLISHED ITS INTENT? IN ORDER TO ANSWER THAT, LET ME DEAL WITH SEVERAL ASPECTS OF THE LAST TWO REPORTS. THE 1981 REPORT WAS ORGANIZED BY GENERIC POLICY ISSUES AND FUNCTIONAL AREAS. FROM OUR PERSPECTIVE IT WAS NOT VERY USEFUL. FOR ONE THING, WE WERE COLLECTIVELY QUITE FAMILIAR WITH THE SUBJECT MATTER. THAT IS, WE HAD ENOUGH EXPERTISE IN ALL THE AREAS COVERED BY THE REPORT SO THAT WE LEARNED NOTHING NEW. THE REPORT OCCASIONALLY DESCRIBED ADMINISTRATION POLICY THAT WE HAD DEVELOPED, AND THAT WAS NOT VERY INFORMATIVE TO US. WE HAVE BEEN USING THE PRESIDENT'S ANNUAL SCIENCE AND TECHNOLOGY REPORT TO THE CONGRESS AS THE PRINCIPAL DOCUMENT FOR ARTICULATING POLICY, SO USING THE FIVE YEAR OUTLOOK FOR THAT PURPOSE IS REDUNDANT.

THE 1982 FIVE YEAR OUTLOOK DEALT WITH SELECTED AREAS OF FUNDAMENTAL SCIENCE AND ENGINEERING. IT PROVIDED AN INTERESTING SURVEY OF THOSE AREAS, BUT AGAIN IT WAS NOT INFORMATIVE TO THOSE OF US WHO HAD EXPERTISE IN THOSE AREAS. WE DID, HOWEVER, REORGANIZE AND EDIT THE INTRODUCTION AND INCORPORATED IT AS A CHAPTER OF THE 1982 ANNUAL SCIENCE AND TECHNOLOGY REPORT.

WE HAVE NO EVIDENCE THAT THE FIVE YEAR OUTLOOK HAS FORCED ANY HIGH LEVEL REASSESSMENT OF EXECUTIVE BRANCH PLANS OR ACTIONS. CERTAINLY IT HAS NOT PROVED USEFUL AS A MEANS OF IDENTIFYING POLICY ISSUES FOR THE ATTENTION OF OUR OFFICE.

COULD THE REPORT ACCOMPLISH ITS INTENT? THE ANSWER TO THAT REQUIRES AN EXAMINATION OF HOW SCIENCE AND TECHNOLOGY POLICY ISSUES ARE IDENTIFIED AND DEALT WITH IN PRACTICE. THE LANGUAGE PERTAINING TO THE FIVE YEAR OUTLOOK IN PUBLIC LAW 94-282 SUGGESTS THAT SCIENCE AND TECHNOLOGY ISSUES ARE DISTILLED FROM A SYSTEMATIC ANALYSIS OF A UNIVERSE OF POTENTIAL PROBLEMS. IN PRACTICE WE FIND THAT SCIENCE AND TECHNOLOGY POLICY IS NOT MADE IN ISOLATION FROM NATIONAL POLICY. SCIENTIFIC OR TECHNICAL CONTENT OF A SCIENCE OR TECHNOLOGY POLICY ISSUE IS ONLY ONE, FREQUENTLY SUBORDINATE, FACTOR IN DETERMINING WHAT CONVERTS A SCIENTIFIC PROBLEM INTO A NATIONAL ISSUE. A NATIONAL SCIENCE OR TECHNOLOGY POLICY ISSUE HAS TO BE TIMELY, POLITICALLY IMPORTANT, AND THE GOVERNMENT MUST BE A NECESSARY PARTICIPANT. IT IS VERY HARD FOR SCIENTISTS TO INCLUDE THESE FACTORS IN THEIR ANALYSES, PARTICULARLY A YEAR OR MORE IN ADVANCE OF PUBLICATION.

THUS WE FIND THAT THE FIVE YEAR OUTLOOK IN ITS CURRENT FORM LAGS RATHER THAN LEADS THE ISSUE IDENTIFICATION AND RESOLUTION PROCESS. I THINK THE TIME LAG IS FURTHER INCREASED BY THE PROCESS OF REVIEWING AND PRODUCING SUCH A REPORT. THE REVIEW

PROCESS ALSO RESULTS IN A PRODUCT THAT IS MORE BLAND THAN THE ORIGINAL. BY THE TIME THERE IS A REASONABLE CONSENSUS ON AN ISSUE IN THE SCIENTIFIC OR TECHNICAL COMMUNITY, AND A REPORT IS PUBLISHED, THE PROBLEM IS PROBABLY ALREADY BEING WORKED ON.

WHAT, THEN, ARE SOME ALTERNATIVES? TIMELY IDENTIFICATION OF SCIENCE AND TECHNOLOGY ISSUES WILL ALWAYS HAVE TO BE DONE IN A DYNAMIC ENVIRONMENT ON A CONTINUING BASIS. OUR OFFICE IS IN CONSTANT CONTACT WITH THE SCIENCE AND TECHNOLOGY COMMUNITY AS WELL AS GOVERNMENT AGENCIES AND CONGRESS. AS YOU KNOW, IMPORTANT ISSUES ARE DISCUSSED AMONG THESE GROUPS WHENEVER NECESSARY AND NOT ON THE BASIS OF AN ANNUAL REPORT.

THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY ALSO RECOGNIZES THE NEED FOR PERIODIC REVIEW AND ASSESSMENT OF ISSUES, BUT WE DO IT ANNUALLY AS AN INTENSIVE STAFF ACTIVITY RATHER THAN RELY ON AN EXTERNALLY PRODUCED DOCUMENT. THAT WAY, THE INFORMATION WE USE IS CURRENT AND WE ARE ABLE TO FOCUS ON THE MULTIPLE FACETS OF EACH ISSUE AND EXPLORE THEM TO WHATEVER DEPTH SEEMS WARRANTED.

ONE ACTIVITY WHICH WE HAVE FOUND USEFUL IN THE PAST YEAR AND A HALF HAS BEEN THE PRESENTATION OF TOPICAL BRIEFINGS BY THE NATIONAL ACADEMY OF SCIENCES TO THE PRESIDENT'S SCIENCE ADVISOR, DR. GEORGE A. KEYWORTH. THESE BRIEFINGS WERE PRESENTED IN THE FALL OF 1982 AND ALSO IN THE FALL OF 1983. IN ALL, 12 BRIEFINGS HAVE BEEN PRESENTED, AND THE BRIEFING PAPERS HAVE

BEEN PUBLISHED IN TWO REPORTS BY THE NATIONAL ACADEMY. THE BRIEFINGS WERE PREPARED IN RESPONSE TO A REQUEST FROM DR. KEYWORTH. TOPICS WERE SELECTED BY OUR OFFICE FROM A LIST RECOMMENDED BY THE NATIONAL ACADEMY. THE SPECIFIC CHARGE TO EACH TOPICAL PANEL WAS TO CRITICALLY ASSESS ITS FIELD AND TO IDENTIFY THOSE RESEARCH AREAS WITHIN THE FIELD THAT WERE LIKELY TO RETURN THE HIGHEST SCIENTIFIC DIVIDENDS.

THE TOPICAL BRIEFINGS HAVE SEVERAL FEATURES WHICH MAKE THEM USEFUL:

- THEY ARE PREPARED AND PRESENTED BY EXPERTS IN THEIR FIELDS.
- THEY ARE TIMELY.
- THEY ARE USUALLY FOCUSSED AND CONCISE.
- THE BRIEFING APPROACH ALLOWS FOR INTERACTION AND DISCUSSION.

THESE FEATURES NEED TO BE KEPT IN MIND WHEN CONSIDERING THE POTENTIAL VALUE OF ISSUE-ORIENTED STUDIES. WHILE THE BRIEFINGS ARE AIMED AT NEAR-TERM FUNDING PRIORITIES, THE BRIEFING PAPERS HAVE FAR MORE OVERALL IMPACT THAN THE TYPE OF MATERIAL COVERED IN THE 1982 FIVE YEAR OUTLOOK.

IN SUMMARY, THE FIVE YEAR OUTLOOK REPORT IN ITS PRESENT FORM IS GOOD FOR SURVEYING SCIENCE AND TECHNOLOGY PROBLEMS. IT HAS NOT DEMONSTRATED THAT IT CAN FULFILL ITS ORIGINAL INTENT, THAT IS, TO IDENTIFY SCIENCE AND TECHNOLOGY ISSUES FOR POLICY CONSIDERATION. IF IT IS TO BE READ AT THE POLICY-MAKING LEVEL IT NEEDS TO SAY SOMETHING NEW, AUTHORITATIVE, AND USEFUL, AND SAY IT BRIEFLY.

THIS CONCLUDES MY FORMAL PRESENTATION. I WOULD BE PLEASED TO ANSWER ANY QUESTIONS FROM THE COMMITTEE.

Mr. **Fuqua**. Thank you very much, Dr. Ling.

As each year the President receives an economic report—there's one made—Economic Report of the President—could something of that type for science and technology be a model for what we're looking for, for trends, for outlooks and other things that are factors that must be considered in science and technology?

Dr. **Ling**. I think we've tried to do that with the annual science and technology report. When I talk about the Five-Year Outlook here, I guess I have difficulty separating it from the annual report because we have so much involvement—much more involvement in the annual report. I would say that, yes, we've been moving in that direction. What we are trying to do with the annual report is make it a policy document, and also a report on activities, but I think this time around, in the latest report, we have tried to include this sort of an outlook type of approach, and I don't see why we can't continue doing that. In fact, probably with continuing discussion with you and your staff, we could perhaps move it in the direction of becoming something even more useful to you.

Mr. **Fuqua**. Is the 5-year timeframe—that was picked out of the air, maybe it should be 10 years, or maybe you suggest—I don't mean to say you suggest, but it be 1 year. We were looking more for long range, because you can't turn on and off science and technology policy like a spigot of water, and 5 years seemed to be an adequate time to plan ahead. Does the 5 years cause problems? Or maybe it should be more or less? Maybe 2 years, 3 years?

Mr. **Ling**. I don't think so. I think that certainly 5 years—at least in my view—sets kind of an upper limit on it. As you know, Mr. Chairman, we certainly have to work at least 2 years ahead because of the budget process. So I think what actually happens is that—and that's why I use the term in my statement—when we say "mid-range,"—we are really thinking 2 to 5 years, and I think when we say "Five-Year Outlook," it's probably not bad. It probably puts the right kind of bound on what we're talking about.

Mr. **Fuqua**. Well, we've also been looking at the idea, and, as a matter of fact, I introduced a bill several years ago, and I hope that we can ultimately go to that as a multiyear authorization, particularly for R&D activities, so that it gives some long range continuity to programs and we more firmly know the direction that we're headed and spend a lot of our other time, rather than authorizing—taking bills to the floor and so forth—that we can do oversight work and try to better understand some of the problems and maybe redirect programs and priorities as they develop.

So I agree with you. I think it's about a 2- to 5-year period that we're really talking about and I agree also that 5 years is a rather optimum time frame.

Were you wishing to comment on that? I was just making a statement, not necessarily a question.

Dr. **Ling**. I am encouraged to hear about multiyear, the possibility of multiyear funding authorization because it certainly has been a problem that has plagued the scientific community, and again, if one were to talk about something beyond 5 years, I would say—you know, if you start talking about 10 years off, you really start getting into the futurology business and I think we've all agreed that that's not—that that is more speculation than practicality.

Mr. Fuqua. Mr. Brown.

Mr. Brown. Mr. Chairman, I apologize for not being here and I missed Dr. Ling's statement so I'm hesitant to comment on that.

Mr. Fuqua. I'll come back then.

Mr. MacKay.

Mr. MacKay. Dr. Ling, it seems to me that in Dr. Low's testimony, he identified that the primary audience for this "Five-Year Outlook Report" is the Congress, and it seems to me, as I understand it, it was a report to be developed with the responsibility, almost like the oversight responsibility of getting it developed in your office, NSF having that specific responsibility, but it was a report to us, and it seems to me that in your testimony, you're saying the report is not useful to you because you already know what's in it.

It doesn't seem to me that addresses the issue of this hearing, which is, how could it be useful to us? I think if the question was whether you knew what was in it, we would never have the law. The question was, we didn't know what you were doing.

Mr. Ling. Well, I think we tried to remedy that by redirecting the annual report. So that we are trying to incorporate elements of that into the annual report, and I think from our perspective, it's a better—that would be a better means of communication, to do it annually, and to incorporate an outlook-type feature of it, rather than go to sort of sporadic issuances of "Five-Year Outlooks."

Mr. MacKay. Let me just give a specific question that would be—I would be very interested in knowing the answer to this question.

We were, prior to the present administration, committed as a Nation to a course of energy independence and alternative energy sources, and there was a major policy shift. I think we wouldn't have to argue that. The Reagan administration took the position that the more productive thing would be to concentrate our efforts.

Now, I'd like to have someone evaluate that policy shift. What have we gotten out of the money that has been spent in the last 3 years, going down the road we're now going down, as contrasted to the one we were going down before? Now, is it possible or not possible that an independent evaluation could be made of that? It seems to me that's a policy question.

Dr. Ling. That's true. Certainly from our perspective, as you know, we have shifted toward the basic research, and the big change in energy was to move away from the demonstration and development and commercialization activities and back into the—into the basic—the basic science, which is the underpinning of that.

We have not done any major assessment of what has been the impact. Perhaps something like that would be desirable.

Mr. MacKay. Well, I'm not saying that it would have to be done from a preconceived point of view, but I think the country has a great interest in that. Certainly the question of energy independence is at the heart of the issue of what's going on in Lebanon and a number of other things. Those countries remain indispensable to our policies, so long as we're not energy independent.

Are we making more progress now than we were before? I would like to know some answers to that. And it seems to me that's the kind of question that this legislation was designed to deal with.

Dr. LING. Well, I don't think you can do that. Maybe even 3 years—certainly 2 years, I think, is too short a period. One really needs to take on—allow the thing to work, allow some of these policies to work themselves out, and then take a look and see if they've—certainly, on an annual basis, we can't do that.

Probably the way to assess this, if the Congress really needs this sort of thing, is to do it every 4 or 5 years and perhaps have topical reviews of that type, if you feel those are necessary.

Mr. MACKAY. All right. Thank you.

Thank you, Mr. Chairman.

Mr. FUQUA. Mr. Brown.

Mr. BROWN. Dr. Ling, I appreciate the point that you made about the need to consider the most effective way in which this exercise can be conducted and the statements that you've made about the usefulness of the briefings which have been presented. And I think it's clear that that is something that the executive office probably needs and that you found a very effective way to get it, and I compliment you on that.

I'm reminded, as I mentioned earlier, of the experience which the Congress has gone through with the Office of Technology Assessment, which has had its ups and downs, as you know, and the work that Dr. Gibbons has gone to in order to find some effective way to relate the work that they're doing to the needs of the Congress. And that has gradually evolved into a more sophisticated process and was originally at least used—or I don't know whether I should say originally contemplated, because I don't think we can foresee the method by which we're going to be able to benefit from a certain process in all of its futures, in all of its details.

But Dr. Gibbons is now putting a great deal of emphasis on the briefing process to the key Members of Congress who can use the information. And in addition to the more comprehensive and lengthy reports, and so forth, he's doing digests, summaries and even one-page sheets that sort of tickle your interest and get you to look at the—at the other things.

And I mention this just to illustrate that it is rather an important exercise just to find out how you establish the process by which learning takes place as between a particular set of actors. And if I had a criticism to make of your statement, it would be that it neglects the utility of this process to a broader audience than just the Office of Science Technology Policy.

It is not your view that the whole purpose of this was merely to provide information to the President's Science Advisor, is it?

Dr. LING. No, sir. I was simply commenting on its utility to us. I wasn't commenting on it—I'm trying to get across the idea of how we use it and, in its present form, does it help us or doesn't it.

Mr. BROWN. Well, I think that's a useful perspective.

Some of the members of the committee here, in their earlier questions, which I'm sure you probably heard, seemed to be critical of the fact that there was not included specific policy recommendations. And we've gone through that exercise before with OTA. And the concensus is that Congress ought to make the policy decisions, not have OTA tell us what the preferred policy decisions were.

And I think that that would hold true of the "Five-Year Outlook." I don't think we need the Academy—much as I respect it—

to tell us what the important priorities are. That's a political decision.

I would say the same thing with regard to the Science Advisor and to the President. We appreciate the advice of the President and the Science A[illegible]n policy, but I think most Members of Congress feel tha[illegible]n independent branch of Government and that we ought t[illegible]der those recommendations and arrive at our own decisions. And I think we tend to look at this process in the light of how we can improve our capacity to make policy.

Now that is the approach that I am taking here, and I haven't been satisfied with the process, either, completely. But my approach has been generally to see what modifications could be adopted that would allow this process to be of even greater value to us.

Let me ask you this to comment on. It has seemed to us on this committee over the years that we can't make good science policy unless there is a scientifically literate and understanding constituency which is willing to support that policy, and that this process can contribute to that. And it does not mean that everything it says has to be absolutely new knowledge that isn't known to policymakers, because when you are dealing with a constituency, a national public, most of them are not going to be very well informed about science, and this is a revelation to them to see the whole perspective of science policy.

Could you comment on the utility of that aspect of it?

Dr. LING. Well, I mention in my statement that I think, as a survey document, the "Five-Year Outlook Report" certainly have—had—they are good survey documents, and I'm sure that they will be often quoted by people outside the Government. There is certainly that utility.

But, again, focusing back on—and if that is a necessary part of the total policy realm, then, you know, so be it. I think as far—from our perspective, in terms of the immediate needs of today, the immediate needs of putting the budget together, it hasn't had the kind of impact that the briefings have had.

I might add, again in terms of the briefings, what's good about them is that they are current and they allow an interaction, and the reports—particularly this year, for instance, the briefings were concluded in sort of the October/November timeframe, and the reports are already out. And that is really something. And to me, making those kinds of things available to a broader audience would probably, I think, tighten up the timeframe a little bit, because the problem with the other one is too much lag.

Mr. BROWN. Well, I have no problem with that, and I commend you for incorporating those briefings into the overall policy and budget process. I think that's a very valuable addition.

Mr. FUQUA. Thank you, Mr. Brown.

I'd like to say that I agree with the statement of Mr. Brown. It has made many—and particularly about the briefings that you have, and commend you for those.

But as the previous two witnesses indicated and we discussed, we need more than just a menu of opportunities of things that need to be done. We need some priorities. Certainly certain forms of research have higher priorities than others, maybe more long-range opportunities. For instance, say, in fusion energies, much more far ranging than the immediate results. Others have a more immediate impact.

And I think what we need to assist us in our decisionmaking process, is what are the thoughts of the administration and in the Office of OSTP in a report where you see the priority. We may not always agree. We may have different priorities and different reasons for them, but I think it's very helpful at least to have the benefit of their thinking in these outlook reports so that we can, and the administration, have priorities that they place on items, as you certainly do, and rightfully so.

And we want to thank you very much for being here this morning, Dr. Ling. We appreciate your contribution.

Dr. LING. Thank you.

Mr. FUQUA. Our next witnesses will be Dr. Richard A. Rettig, a professor of social science and chairman of the department of social sciences at the Illinois Institute of Technology in Chicago; and also I'd like to join him at the table Dr. Russell Court and Dr. Elizabeth Cort, principal investigators, Survey of Utilization of Five-Year Outlooks, from Maryland.

Dr. Rettig, we'll hear from you, and then from Dr. Cort and Dr. Cort, and then we'll have some questions.

STATEMENT OF DR. RICHARD A. RETTIG, PROFESSOR OF SOCIAL SCIENCE AND CHAIRMAN, DEPARTMENT OF SOCIAL SCIENCE, ILLINOIS INSTITUTE OF TECHNOLOGY, CHICAGO, IL

Dr. RETTIG. Thank you, Mr. Chairman and members of the committee.

My name is Richard Rettig. I am professor of social science and chairman of the department of social sciences at the Illinois Institute of Technology.

As far as my connection to the Five-Year Outlook on Science and Technology, I served from 1979 to the present as a member of the National Science Foundation's Oversight Panel on the outlook; I wrote a chapter in the American Association for the Advancement of Science contribution to the outlook in 1981; and, in January 1982 at the AAAS meeting, I gave a somewhat peevish speech on the process of preparing the outlook.

Thus, I played a bit part in the process you are considering today, but have neither a large personal nor institutional stake in it. So, in the guise of a disinterested, objective academic expert, I offer you my personal, and perhaps idiosyncratic, views.

You asked in your letter, Mr. Chairman, about the usefulness of the report to the Congress. I would agree with the others who spoke that, on that, you are more expert than any of us. In light of the study of several years ago by Representative David Obey, which showed that the average Member of the House spends 11 minutes a day reading, I suspect that the first and second reports represented an undigestable mass of information. I've not read the 1983 combined Annual Report and Outlook and must withhold comment. It appears, however, by virtue of its brevity, to be a major improvement.

Regarding the language of section 206(a), paragraphs 1 through 6, of Public Law 97-375, I would make two major observations and a basic distinction. First, on the first paragraph, in terms of obtaining a timely statement of "the President's current policy" for science and technology, as required by that paragraph, that will remain difficult unless it's in the President's interest to provide one, or the time cost to the Office of Science and Technology Policy is low, or the length is short and the content superficial.

This particular statutory requirement is not action forcing, in my judgment, as are budgetary, legislative, and regulatory issues. Unless the requirement helps the President do his job better, or aids OSTP in fulfilling its obligations to him, there will be little incentive for him to comply.

Second, however, in distinguishing between the first paragraph and paragraphs 2 through 6, which pertain primarily to strategic or policy planning about the emerging issues of science and technology of national consequence, these paragraphs constitute a general open-ended order which lacks clear criteria about comprehensiveness of scope and thoroughness of coverage, and provides little guidance to the administration about the time, personnel or financial inputs required to prepare an acceptable response. In simple administrative terms, it is not surprising that OSTP originally sloughed its responsibility onto NSF and the latter contracted with the National Academy of Sciences and others to do the bulk of the work.

Several possible modifications suggest themselves, depending, of course, on what the Congress wishes to achieve through this portion of the statute. For one thing, the five paragraphs in question might be reduced to a single paragraph which indicates more clearly than the present language what the Congress wishes to see on a regular basis. Alternatively, the Congress might consider a procedure by which it writes the President a letter every other year to specify the substantive topics on which it would like to have addressed within the general framework of section 206.

The questioning this morning by various members of the committee indicated that the report was not entirely responsive to various concerns they had. And if the committee were to set those concerns out on a regular basis, one might get more focused response to the document.

Third—and this will rank as perhaps the most novel idea of the day, I suppose—the Congress might choose to fulfill the intent of section 206 itself, using those resources directly under its control.

Let me amplify the reasoning behind this last suggestion. First, relying on the executive branch will usually result in OSTP and NSF contracting out most of the work, a bad practice, in my view, for policy-related matters, and one that's all too characteristic of our modern Federal Government.

It was this contracting-out process I criticized 2 years ago in my AAAS speech, a process which creates extended and quite tenuous relationships between the question asker, the Congress, the question-and-answer manager, the NSF, on behalf of the OSTP, and the question-answerer, the National Academy of Sciences, other contractors, Federal agencies, and individual authors.

This latter group, I submit, have no real understanding of what Congress wants, and per force, must impose their own sense of your intention on their work. The problem, in short, resides in the design of the system.

Second, if Congress managed the section 206 process directly, it would soon discover the time, personnel and financial costs of getting answers to its questions and then be able to judge the worth of the product relative to its costs and in relation to other competing demands.

Third, if Congress were to manage the process itself, dealing directly with the scientific and technological communities, one beneficial effect could be to strengthen the institutions of democratic government. Scientists and engineers orient themselves primarily to the departments and agencies of Federal Government that dispense research and development funds and deal with other aspects of science and technology like use or regulation.

The number of transactions they have between the executive branch, when compared to the Congress, is just substantially greater. They are, relatively speaking, weakly oriented to elections and the Congress, the primary instiutions of popular control of government.

Suggestions they make for improving the management and governance of the scientific and technological enterprise often lead to proposals like a "science court" that would separate politics from decisionmaking about science and technology, proposals both infeasible and undesirable.

Less often—much less often do they suggest ways to improve the involvement of the Congress in the management of science and technology. Perhaps it is time to consider changing the institutional reality that change, that shapes orientations and perceptions. Perhaps the Congress should actively consider direct management of the 206 process itself.

Is the Congress capable of assuming this responsibility? I believe so. In any event, it is far from clear they would be less well served by doing it directly than by asking the executive branch to do it for them. There was a time 20 years ago when the Congress depended very extensively upon the President and the then Office of Science and Technology for leadership in science and technology matters, but many changes have occurred since President Eisenhower appointed Dr. Killian as Science Advisor in 1957 and since President Kennedy created the OST in 1962.

For one thing, that centralized unit finds it harder to keep track of everything of consequence in science and technology. For another thing, the elite cadre of advisors who came out of World War II, who went to school, so to speak, in World War II, has now passed from the scene. The contemporary generation of key scientists and engineers, by contrast, have gone to many different schools—the National Space Program, medical research, weapons laboratories, industrial research and development and the regulation of health safety and environment.

They manifest none of the coherence of the older group and their differences count for more than their similarities. This change alone makes it harder for a centralized executive branch agency to monitor developments in science and technology.

A decentralized institution like the Congress can perhaps relate to this diversity more effectively than a centralized administrative entity. This diversity among scientists and engineers is paralleled in the executive branch in both the growth in number and diversity of executive branch agencies.

On the other hand, the Congress, during this period, has increased it own involvement, resources, and capabilities for dealing with science and technology through the activities of its Members, its committees and subcommittees and has greatly augmented its personal, committee, and institutional staff. It is able to draw upon the General Accounting Office, the Congressional Research Service, the Office of Technology Assessment and the Congressional Budget Office.

Its worth considering whether the Congress is not now better equipped to fulfill the aspirations of section 206 than is a centralized executive branch agency.

Let me make a different but related point. The print and electronic media today employ many more talented science and technology journalists than was true 20 years ago. These journalists aggressively cover emerging scientific and technological developments, report on their immediate and long-term implications.

In addition, numerous magazines today, devoted exclusively to science and technology, command a very important readership. Relative to the point made a moment ago, Mr. Brown, about the literacy of the public, I think that is far more served—far more effectively served by that group of people than by the Five-Year Outlook Report on Science and Technology.

Furthermore, a veritable army of researchers in universities and other institutions can be assembled quite readily on most topics of current interest. In short, there are far more "helpers" today than ever before on whom the Congress can call.

My point is simple: As the executive branch has become less able to contend with the increasing diversity of science and technology through a centralized entity, Congress has increased its capability; and a corresponding increase has occurred in the number of journalists and academic and nonacademic researchers who track the "emerging issues" of science and technology.

The conditions may be propitious for Congress to develop means for directly engaging the scientific and technological communities, rather than relying as extensively on the executive branch, as it has done in the past.

Posing of sharp questions is one of the requisites, it seems, to getting focused answers. If it chooses, for example, it can contract directly with the National Academy of Sciences, as Mr. Daddario of this committee demonstrated in the late 1960's, and to good effect. Two or three reports that were produced for this committee were of very high quality.

It may be appropriate, then, for Congress to consider assuming direct responsibility for the section 206 process.

Thank you very much.

[The prepared statement of Dr. Rettig follows:]

PREPARED STATEMENT OF RICHARD A. RETTIG, PH.D., PROFESSOR OF SOCIAL SCIENCE AND CHAIRMAN, DEPARTMENT OF SOCIAL SCIENCES, ILLINOIS INSTITUTE OF TECHNOLOGY, CHICAGO, IL

Mr. Chairman, Members of the Committee, my name is Richard A. Rettig. I am Professor of Social Science and Chairman of the Department of Social Sciences at the Illinois Institute of Technology. Regarding the Five-Year Outlook on Science and Technology, I have served from 1979 to the present as a member of the National Science Foundation's Oversight Panel on the Outlook; I also wrote a chapter in Teich and Thornton, eds., Science, Technology, and the Issues of the Eighties: Policy Outlook, the contribution of the American Association for the Advancement of Science to the second Outlook; and, in January 1982, at the annual meeting of the AAAS, I gave a peevish speech on the process of preparing the Outlook.

Thus, I have played a bit part in the process you are considering today, but have neither a large personal nor institutional stake in it. So, in the guise of a disinterested, objective academic expert, I offer you my personal, and perhaps idiosyncratic, views on the subject.

You asked in your letter, Mr. Chairman, about the usefulness of the report to the Congress. On that you are more expert than anyone. In light of the study of several years ago by Rep. David Obey, which showed that the average Member of the House spends eleven minutes a day reading, I suspect that the first and second reports represented an undigestable mass of information. I have not read the 1983 combined Annual Report on Science and Technology and Outlook and must withhold comment on it.

Regarding the language of Sec. 206(a)(1-6) of Public Law 97-375, I would make two major observations. First, obtaining a timely "statement of the President's current policy . . . for science and technology," as required by the first paragraph, will remain difficult unless it is in the President's interest to provide one, or the time cost to the Office of Science and Technology Policy is low, or the length is short and the content superficial. This particular statutory requirement is not "action forcing" as are budgetary, legislative, and regulatory issues. Unless the requirement helps the President do his job better, or aids OSTP in fulfilling its obligations to him, there will be little incentive for him to comply.

Second, paragraphs (2) through (6), which pertain primarily to strategic or policy planning about the "emerging issues" of science and technology of national importance, constitute a general, open-ended order which lacks clear criteria about comprehensiveness of scope and thoroughness of coverage and provides little guidance to the administration about the time, personnel, or financial inputs required to prepare an acceptable response. In simple administrative terms, it is not surprising that OSTP originally sloughed its responsibility onto NS and the latter contracted with the National Academy of Sciences and others to do the bulk of the work.

Several possible modifications suggest themselves, depending, of course, on what the Congress wishes to achieve through this portion of the statute. For one thing, the five paragraphs in question might be reduced to a single paragraph which indicates more clearly than the present language what the Congress wishes to see on a regular basis. Alternatively, the Congress might consider a procedure by which it writes the President a letter every other year to specify the substantive topics it would like to have addressed within the general framework of Sec. 206. Third, the Congress might choose to fulfill the intent of Sec. 206 itself, using those resources directly under its own control.

Let me amplify the reasoning behind this last suggestion. First, relying on the executive branch will usually result in OSTP and NSF "contracting out" most of the work, a bad practice, in my view, for policy-related matters and one that is all too characteristic of modern government. It was this "contracting out" process I criticized two years ago in my AAAS speech, a process which creates extended, and quite tenuous, relationships between the question-asker (the Congress), the question-and-answer manager (the NSF for OSTP), and the question-answerer (the NAS, other contractors, the federal agencies, and individual authors). This latter group, I submit, have no real understanding of what the Congress wants and, perforce, must impose their own sense of your intention on their work. The problem, in short, resides in the design of the system.

Second, if Congress managed the Sec. 206 process directly, it would soon discover the time, personnel, and financial costs of getting answers to its questions. It would then be able to judge the worth of the product relative to its costs and in relation to other competing demands.

Third, if Congress were to manage the process itself, dealing directly with the scientific and technological communities, one beneficial effect would be to strengthen the institutions of democratic government. Scientists and engineers orient themselves primarily to the departments and agencies of the federal government that dispense research and development funds and that deal with other aspects of science and technology, like use or regulation. They are, relatively speaking, weakly oriented to elections and the Congress, the primary institutions of popular control of government. Suggestions for improving the management and governance of the scientific and technological enterprise often lead to proposals like a "science court" that would separate politics from decision-making about science and technology, proposals that are both infeasible and undesirable. Much less often do they suggest ways to strengthen the involvement of Congress in the management of science and technology. Perhaps it is time to consider changing the institutional reality that shapes orientations and perceptions. Perhaps the Congress should actively consider direct management of the Sec. 206 process.

Is the Congress capable of assuming this responsibility? I believe so. In any event, it is far from clear that they would be less well served by doing it directly than by asking the executive branch to do it for them. There was a time twenty years ago when the Congress depended very extensively upon the President and the then-Office of Science and Technology for leadership on scientific and technological matters. But many changes have occurred since President Eisenhower appointed the Science Advisor to the President in 1957 and President Kennedy created the OST in 1962.

For one thing, it is harder today for a centralized administrative agency to keep track of everything of consequence in science and technology. The elite cadre of scientists and engineers on whom the country depended for so long, and who served it so well, have essentially passed from the scene. They went to "schools" in World War II—the M.I.T. Radiation Laboratory, Los Alamos or some other Manhatten Project laboratory, or elsewhere in the wartime R & D effort. Their common characteristics of youth, training in the physical sciences, and affiliation with a relatively few prestigous universities, when coupled with the World War II experience, suited them well to direct and advise the then much smaller scientific and technical enterprise of the federal government.

Today's generation of key scientists and engineers, by contrast, have gone to many different "schools"—the national space program, medical research, weapons laboratories, industrial research and development, and the regulation of health, safety, and environment. They manifest none of the coherence of the older group and their differences count far more than their similarities. This change alone makes it more difficult for the executive branch to centrally monitor the science and technology enterprise. A decentralized institution like the Congress can perhaps relate to this diversity among scientists and engineers more effectively than a centralized administrative entity.

Growing diversity among scientists and engineers is paralled in other areas. The executive departments and agencies that support, use, and regulate science and technology have increased both in number and diversity. The President has an intrinsically harder time choosing a Science Advisor known to all key constituencies and commanding their respect by prior knowledge and reputation.

The Congress during this time has increased its involvement in science and technology through the numerous activities of its individual Members and its committees and subcommittees. It has also greatly augmented its personal, committee, and institutional staff resources and is able to draw upon the General Accounting Office, the Congressional Research Service, the Office of Technology Assessment, and the Congressional Budget Office. It is worth considering whether the decentralized institution of Congress is not now better equipped to fulfill the aspirations of Sec. 206 than is a centralized executive branch agency.

Let me make a different but related point. The print and electronic media today both employ many more talented science and technology journalists than was true twenty years ago. These journalists aggressively cover emerging and current scientific and technological developments and report on their immediate and long-term implications. In addition, magazines devoted exclusively to science and technology command an important readership today. Furthermore, a veritable army of researchers in universities and other institutions can be assembled quite readily on most topics of current interest. In short, there are far more "helpers" today on whom the Congress can call than was ever the case before.

My point is simple: as the executive branch has become less able to contend with the increasing diversity of science and technology through a centralized entity, the Congress has increased its capability; and a corresponding increase has occurred in the number of journalists and academic and nonacademic researchers who track the "emerging issues"of science and technology. The conditions may be propitious for

Congress to develop means for directly engaging the scientific and technological communities rather than relying as extensively upon the executive branch as it has in the past. If it chooses, for example, it can contract with the National Academy of Sciences, as this Committee under Rep. Emilio Daddario demonstrated in the late 1960s. It may be appropriate for Congress, then, to assume direct responsibility for the Sec. 206 process.

Thank you.

Mr. FUGUA. Thank you very much, Dr. Rettig.

Dr. Cort.

[The biographical sketch of Dr. Cort follows:]

BIOGRAPHICAL DATA

H. Russell Cort

B.A., Dartmouth College, 1950. Major: Psychology
Ph.D., Cornell University, 1960. Major: Experimental Psychology

Positions held:

1. Chairman, Department of Psychology, Ripon College, Wisconsin.
2. Human Factors Specialist, Advanced Systems Engineering, General Electric Co.
3. Senior Associate, Planning Research Corporation.
4. Chairman, Educational Studies Department, Washington School of Psychiatry.
5. Director, Evaluation Systems, General Learning Corporation.
6. Director of Administration, Acting Clinic Director, and Professor, Antioch School of Law.
7. Consultant: D.C. Public Schools and other public and private organizations and agencies.

Main areas of interest: Evaluation research; education; administration.

Elizabeth C. Cort

B.S., Skidmore College, 1954. Major: Art History/English
M.Ed., Boston University, 1967. Major: School Psychology

Positions held:

1. Teacher: Princeton, N.J.; Boston, Mass.; Washington, D.C.
2. Educational Psychologist: Bedford & Brookline, Mass.; Washington, D.C.
3. Consultant: Educational Projects; National Presbyterian School; Antioch School of Law.
4. Assistant Director: Center for Legal Studies, Antioch School of Law.

154 Fleetwood Terrace
Silver Spring, MD 20910
(301) 588-6280

STATEMENT OF DR. H. RUSSELL CORT, AND ELIZABETH CORT, PRINCIPAL INVESTIGATORS, SURVEY OF UTILIZATION OF FIVE-YEAR OUTLOOKS, SILVER SPRING, MD

Dr. CORT. Mr. Chairman, members of the committee, we're pleased to have the opportunity to speak to you today about the study that we're just concluding about people's views of the Five-Year Outlooks.

We would also like to express our appreciation to the National Science Foundation for allowing us to report to you and to use some tables from our report prior to completion of our contract with it.

Let me describe our study briefly. Its purposes were to find out what uses people in the Congress and elsewhere have made of the outlooks, how useful they've been, and what suggestions people may have for improving them.

We collected two kinds of data this past fall. First, we mailed 647 questionnaires to Congress and processed and tabulated the returns. Exhibit 1, and I wish to call your attention to the exhibits which are at the end of this report, and they're numbered in order. I will refer to them; I won't read them entirely. I think they're reasonably straightforward.

Exhibit 1 shows the distribution of the questionnaire and the number of responses for each main category of questionnaire recipient. Of the 179 Members of Congress, legislative assistants and committee staff members who responded, 65, or only 36 percent of the respondents, indicated that they were at least aware of one or more of the outlooks and not all of them had used them.

Second, we called and interviewed samples of people on NSF and NAS mailing or distribution lists. These people were in 46 States, the District of Columbia, and 12 countries. We contacted 492 persons in government, industry, colleges and universities and in scientific and technological foundations and societies. Exhibits 2 and 3 show the categories of people and the numbers of people contacted in each category.

Sixty percent of these people knew of one or more of the three main outlooks, and 40 percent, or 191 persons, were willing to offer opinions in an interview.

I should note that the Government Printing Office has sold several thousand copies of the first two outlooks. We were not able to tap GPO's sales lists within the resources and time limits of this project, but clearly there has been a modest commercial market for the outlooks, as there also has been for the commercial version of the National Academy's part of the outlook.

I would like to summarize our findings by referring to four tables. These are exhibits 4 through 7. These exhibits, like the previous ones, are tables from our report to the National Science Foundation.

The main uses of the outlooks in the Congress, exhibit 4, based on the returns of the questionnaire that we used, have been for preparing hearing background papers, identifying science and technology-related issues for legislative agendas, assessing national needs, and writing speeches and articles.

All three outlooks have been used by at least some people for each of the 17 purposes listed in exhibit 4. The main users, based on our returns, again, it would appear, have been committee staff members, both in the House and in the Senate.

The third, or most recent outlook, has received proportionately more use than the first two. By that, I mean proportionately more people say, yes, they used it for some purpose, proportionately.

Outside the Congress, the most frequent uses of the outlooks, as shown in exhibit 5, were for generally keeping informed about scientific and technological developments, identifying scientific or technological issues, opportunities or problems, preparing professional books, papers or, most often, talks or speeches, and for determining policies or strategies for the department, organization or whatever.

We did not find that the rates of use for particular purposes differed very much among different types of users, by and large. Government agency personnel, scientists in universities, university presidents or vice presidents or research grant coordinators, industry vice presidents of R&D all tended to show roughly the same rate of use for a given purpose.

Both in the Congress and elsewhere, most people rated the outlooks as moderately useful for various purposes. On a scale of 1 to 10, to give a benchmark sort of thing, 10 being highest, average ratings of usefulness by congressional respondents and by people interviewed ranged from about 4 to 7.

For some people in and out of the Congress, the different outlooks have been extremely useful. Some rated them 9 or 10 for some purposes. Others thought they were worthless or a waste of time and money. So there was a range of reaction.

We should note that opinions from OSTP, OMB and NAS are not included in our results, since we did not interview them as part of our samples. We did talk, however, with certain individuals in OSTP and NAS as part of the overall study.

Most people we talked to in our study do not read the outlooks in any systematic or thorough fashion. They tend to be used more like the Encyclopedia Britannica. People tend to skim through them, reading in more detail parts of particular interest to them.

I should note that people clearly use a variety of other sources of information for essentially the same purposes that they use the outlooks. Some of the other sources cited were, of course, professional journals, Annual Science and Technology Reports, Science Indicators, OTA and CRS reports, congressional reports, Scientific American, Science, Science 83, Science Digest, and the Wall Street Journal. This is to name only a few. Dr. Rettig already noted that there are many sources of information available now.

What changes or improvements in future outlooks have people suggested? Suggestions from congressional respondents are shown in exhibit 6. Suggestions from others are shown in exhibit 7.

Without question, there is a ubiquitously-perceived need for better summarizing or highlighting of significant portions. I might interject that part of the data indicated that overwhelmingly, most people find the summaries most useful, either the summary—the 5-Year Outlook reports proper, not the source materials, or the overview chapter in the third Five-Year Outlook.

There's also a need for clearer depiction of changes since the last outlook and what those changes might—are, or might be. Many people seem to use the outlooks to look for trends, and would apparently like assistance in detecting them, even in the form of simple reminders of what has been.

Congressional users are interested in seeing legislative implications, and even if they are only approximate, some idea of priorities. The latter would seem to be at least a short-term immediate need.

Many people are interested in and concerned about anticipated social and economic costs of emerging scientific and technological developments. While a number of people we talked to said those were impossible to determine, they also felt that continued work on ways and means of trying to project them was important and worthwhile.

We received many other suggestions for improvement of the FYO's, the Five-Year Outlooks, from Congress and from people with whom we talked. Suggestions were for changes in content, in organization of the reports, in presentation, in frequency of their publication, in who prepares them and how they're disseminated.

Our results suggest that dissemination in the Congress has not been as effective as it could be. One criticism that came up that was made by people both in and out of the Congress was that the outlooks, as they had been conceptualized and implemented, simply justify past programs and practices. There are people who think that what is needed is an analysis suggesting what might be, rather than what per force will be if there is no change in direction. This might take the form of alternative, plausible scenarios.

There is no question from the data gathered in our study that a wide range of people use the outlooks in sundry ways. Those people also have available, as mentioned, a number of other kinds of material and information produced by the Government and other sources that they use for the same purposes. The outlooks, nevertheless, have been serving an educational and "horizon-scanning" function for many people, as well as serving more specific reference purposes.

Thank you very much. We would be happy to answer questions.

[The prepared statement of Dr. Cort follows:]

STATEMENT OF DR. H. RUSSELL CORT AND ELIZABETH C. CORT, CO-PRINCIPAL INVESTIGATORS OF AN EVALUATION OF THE FIVE-YEAR OUTLOOKS FROM THE USERS' POINT OF VIEW

Before the

COMMITTEE ON SCIENCE AND TECHNOLOGY OF THE
UNITED STATES HOUSE OF REPRESENTATIVES

January 24, 1984

Mr. Chairman and Members of the Committee:

We are pleased to have the opportunity to speak with you today about the study we are just concluding about people's views of the Five-Year Outlooks. We would also like to express our appreciation to the National Science Foundation for allowing us to report to you and to use some tables from our report prior to the completion of our contract with it.

Let me describe our study briefly. Its purposes were to find out what uses people in the Congress and elsewhere have made of the Outlooks, how useful they have been, and what suggestions people have for improving them.

We collected two kinds of data. First, we mailed 647 questionnaires to Congress and processed and tabulated the returns. Exhibit 1 shows the distributions of the questionnaire and the number of responses for each main category of questionnaire recipient. Of the 179 Members of Congress, legislative assistants and committee staff members who responded, 65 (or only 36 percent of the respondents) indicated they were at least aware of one or more of the Outlooks, and not all of them had used them.

Second, we called and interviewed samples of people on NSF and NAS mailing or distribution lists. These people were in 46 states, the District of Columbia, and 12 countries. We contacted 492 persons in government, industry, colleges and universities, and in scientific and technological foundations and societies. Exhibits 2 and 3 show the categories of people and the numbers of people contacted in each category. Sixty percent of these people knew of one or more Outlook, and 40 percent (191 persons) were willing to offer opinions in an interview.

The Government Printing Office has sold several thousand copies of the first two Outlooks. We were not able to tap GPO's sales lists within the resources and time limits of this project. Clearly, there has been a modest commercial market for the Outlooks, as there also has been for the commercial version of the NAS part of the Outlook.

I would like to summarize our findings by referring to four tables (Exhibits 4-7). These exhibits, like the previous ones, are tables from our report to the National Science Foundation.

The main uses of the Outlooks in the Congress (Exhibit 4) have been for:

- Preparing hearing background papers;
- Identifying S&T-related issues for legislative agendas;
- Assessing national needs; and
- Writing speeches and articles.

All three Outlooks have been used by at least some people for each of the 17 purposes listed in Exhibit 4. The main users, it appears, have been Committee staff members, both in the House and Senate. The third or most recent Outlook has received proportionately more use than the first two.

Outside the Congress the most frequent uses of the Outlooks (as shown in Exhibit 5) were for:

- Generally keeping informed about S&T developments;
- Identifying S or T issues, opportunities or problems;
- Preparing professional books, papers or, most often, talks or speeches; and
- Determining policies or strategies.

We did not find that the rates of use for particular purposes differed very much among types of users, by and large. Government agency personnel, scientists in universities, university presidents or vice-presidents or research grant coordinators, industry vice-presidents of R&D all tended to show roughly the same rate of use for a given purpose.

Both in the Congress and elsewhere, most people rated the Outlooks as moderately useful for various purposes. On a scale of 1 to 10, 10 being highest, average ratings of usefulness by Congressional respondents and by people interviewed ranged from about 4 to 7. For some people in and out of Congress, the different Outlooks have been extremely useful (some rated them 9 or 10). Others thought they were worthless, a waste of time and money.

We should note that opinions from OSTP, OMB and NAS are not included in our results, since we did not interview them as part of our samples. We did talk, however, with certain individuals in OSTP and NAS as part of the overall study.

Most people we talked to in our study do not read the Outlooks in any systematic or thorough fashion. The Outlooks are used more like the Encyclopedia Britannica. People tend to skim through them, reading in more detail parts of particular interest to them. People use a variety of other sources of information for the same purposes as the Outlooks. Some of the other sources cited were professional journals, the Annual Science and Technology Report, Science Indicators, OTA and CRS reports, Congressional reports, Scientific American, Science, Science 83, Science Digest, and The Wall Street Journal.

What changes or improvements in future Outlooks have people suggested? Suggestions from Congressional respondents are shown in Exhibit 6. Suggestions from others are shown in Exhibit 7.

Without question, there is a ubiquitously-preceived need for better summarizing or highlighting of significant points. There is also a need for clearer depiction of changes since the last Outlook, and what those changes are. Many people use the Outlooks to look for trends and would like assistance in detecting them, even in the form of simple reminders. Congressional users are interested in seeing legislative implications and, even if they are only approximate, some idea of priorities. The latter would seem to be a short-term need.

Many people are interested in and concerned about the anticipated social and economic costs of emerging scientific and technological developments. While a number of people we talked with said those were impossible to determine, they also felt that continued work on means of projecting them was important.

We received many other suggestions for improvement of the FYOs, from Congress and from people with whom we talked. Suggestions were for changes in content, in organization of the reports, in presentation, in the frequency of their publication, in who prepares them, and in how they are disseminated. Our results suggest that dissemination in the Congress has not been as effective as it could be. One criticism made was that the Outlooks, as they have been conceptualized and implemented, simply justify past programs and practices. There are people who think that what is needed is an analysis suggesting what might be rather than what per force will be if there is no change in direction. This might take the form of alternative plausible scenarios.

There is no question from the data gathered in our study that a wide range of people use the Outlooks in sundry ways. Those people also have available, as mentioned, a number of other kinds of material and information produced by the government and other sources that they use for the same purposes. The Outlooks nevertheless have been serving an educational and "horizon-scanning" function for many people, as well as serving more specific reference purposes.

Thank you very much. We will be happy to answer questions.

Exhibit 1. Congressional Questionnaire Distribution and Response, by Category.

Category	No. Sent	No. Returned	% of Category Total	No. & % of Respondents Aware of 1 or More FYO 6/	
				N	%
Senators	80	18 4/	22.5%	4	22.2%
Representatives	194	21 5/	10.8%	5	23.8%
Senators' Staff	84	26	31.0%	7	26.9%
Representatives' Staff	202	65	32.2%	18	27.7%
Senate Committee Staff	39	20	51.3%	11	55.0%
House Committee Staff 1/	45	27	60.0%	18	66.7%
Committee Unclassifiable 2/	0	1	--	1	100.0%
Generally Unclassifiable 3/	0	1	--	1	100.0%
Totals	644	179		65	

1/ Includes Executive Directors of the Congressional Clearinghouse on the Future and the Congressional Caucus for Science and Technology.

2/ Could not tell whether respondent was staff member of a Senate or House Committee or Sub-Committee.

3/ Could not determine whether respondent was a staff member of a Committee or of a Member's office.

4/ Includes five Senators who said their policy was not to answer questionnaires.

5/ Includes one Representative with policy of not answering questionnaires.

6/ These are percentages of the respondents in each category, not of the total distribution.

Exhibit 2. Categories and Numbers of Persons Interviewed, and Prevalence of Awareness of One or More FYO.

Category	Category Total	# & % of Persons Contacted		# & % Aware of One or More FYO		# & % Unaware of FYOs	
		N	% [1]	N	% [2]	N	% [2]
1. Federal Government [3]	123	71	57.7	42	59.2	29	40.8
2. NSF Officials	41	26	63.4	26	100.0	0	0.0
3. Former NSB Members	60	19	31.7	18	94.7	1	5.3
4. Current NSB Members	23	6	26.1	6	100.0	0	0.0
5. S & T Societies	166	51	30.7	24	47.1	27	52.9
6. Research Administrators	283	95	33.6	55	57.9	40	42.1
7. SRS/R&D Funds Report	182	48	24.6	18	37.5	30	62.5
8. Governors' Science Advisors	28	6	21.4	3	50.0	3	50.0
9. Pres.-State Academy of Science	32	5	15.6	0	0.0	5	100.0
10. NSF Advisory Committees	576	125	21.7	68	54.4	57	45.6
11. General Lists, U.S. Requestors	45	14	31.1	11	78.6	3	21.4
12. Embassies (Mostly U.S. Overseas)	53	15	28.3	11	73.3	4	26.7
Totals	1,612	481 [4]	29.8	282	58.6	199	41.4

---

[1] These are percentages of the total numbers of persons in each category. Category 1 consists of 7 sub-categories, which were in turn based either on lists provided by NSF or NAS, or on individuals selected in a number of Federal Agencies because of their positions. Thus, there is no category total comparable to those of categories 3-12. Category 2 was based on a sample from the NSF Executive and Mangement Council lists (excluding members of the Office of the Director), plus 20 of 23 Directorate and Division Heads (or their replacements) that were not included in the Council samples. Category 10 is based on 25% samples, on the average, from each of 16 NSF Advisory Committee lists. Categories 3 and 5-9 contain the computer-generated mailing lists provided by NSF. The totals for each of those categories exclude all non-U.S. addressees and all persons contacted in the pre-design study (of which there were 38 in all). Category 10 totals exclude the 16 persons called in the pre-design study.

[2] These are percentages of the number of people contacted in each category.

[3] Does not include OSTP or OMB.

[4] Does not include the 11 librarians given special interviews. If they are included, the total percentage contacted is 30[illegible]

Exhibit 3. Types of Settings and Numbers of People Interviewed, and Prevalence of Awareness of One or More FYO.

Types of Settings	# & % Contacted	# & % Aware of One or More FYO		# & % Unaware of FYOs	
		N	% 1/	N	% 1/
1. Societies, Associations, Foundations, Institutes	65	33	50.8	32	49.2
2. Colleges, Universities	216	117	54.2	99	45.8
3. Local, State, Federal Agencies	125	85	68.0	40	32.0
4. Companies, Corporations	42	24	57.1	18	42.9
5. Other	33	23	69.7	10	30.3
Total	481	282		199	

1/ These are percentages of persons contacted in each type of setting.

Exhibit 4. Uses of FYOs in the Congress: Number and Percentage of Respondents Indicating Each Use 1/

	FYO-1		FYO-2		FYO-3	
	%	N	%	N	%	N
1. Preparing hearing background papers	51.1	23	38.9	21	57.8	26
2. Identifying S&T related issues for legislative agendas	48.9	22	44.4	24	60.0	27
3. Assessing national needs	48.9	22	35.2	19	55.6	25
4. Writing speeches, articles	44.4	20	37.0	20	55.6	25
5. Identifying S&T related issues for oversight agendas	37.8	17	33.3	18	44.4	20
6. Preparing floor remarks	35.6	16	27.8	15	46.7	21
7. Evaluating budget requests	31.1	14	29.6	16	44.4	20
8. Determining oversight priorities	31.1	14	27.8	15	37.8	17
9. Doing foresight or futures research activities	31.1	14	25.9	14	42.2	19
10. Determining legislative priorities	26.7	12	20.4	11	33.3	15
11. Writing legislative reports	24.4	11	24.1	13	26.7	12
12. Dealing with lobbyists, interest groups	24.4	11	22.2	12	35.6	16
13. Responding to inquiries from constituents	24.4	11	25.9	14	40.0	18
14. Proposing legislation	20.0	9	13.0	7	26.7	12
15. Identifying potential witnesses	20.0	9	16.7	9	26.7	12
16. Writing oversight reports	20.0	9	20.4	11	28.9	13
17. Drafting legislation or amendments	17.8	8	16.7	9	22.2	10
18. Other (Please list or describe on back of sheet)	0.0	0	0.0	0	0.0	0
Overall Average per Item 2/	31.8%		27.0%		40.3%	
Median Percentage 2/	32.0%		26.4%		40.1%	

1/ All percentages are based on the number of respondents who indicated awareness of a particular FYO. For FYO-1, N=45; for FYO-2, N=54; and for FYO-3, N=45.

2/ Does not include Item 18, Other.

Exhibit 5. **Uses of FYOs at large: Number and Percentage of Interviewees Indicating Each Use** 1/

Use	FYO-1		FYO-2		FYO-3	
	%	N	%	N	%	N
1. Generally keeping informed on S&T developments	86.6	123	88.3	136	65.7	46
2. Identifying S or T issues, opportunities or problems	50.7	72	55.2	85	41.4	29
3. Preparing professional books, papers or speeches	46.5	66	45.5	70	35.7	25
4. Determining policies or strategies	46.5	66	48.1	74	34.3	24
5. Preparing or recommending organization's development plans or programs	40.1	57	40.3	62	31.4	22
6. Preparing testimony for Congress or state or local legislature	19.7	28	20.1	31	10.0	7
7. Teaching	19.0	27	18.2	28	11.4	8
8. Preparing budgets	17.6	25	22.1	34	14.3	10
9. Proposing or preparing legislation	8.5	12	7.8	12	5.7	4
Overall Average per Item	37.2%		38.4%		27.8%	
Median Percentage	38.0%		38.0%		31.8%	

1/ The percentages for each item and FYO are based on the number of interviewees indicating awareness of the particular FYO. For FYO-1, N=142; for FYO-2, N=154; for FYO-3, N=70.

Exhibit 6. **Suggestions for Improvements: Congressional Respondents.**

Suggestion	Percentage Endorsing [1]	Number
1. Short, 5-10 page summary	75.4	47
2. Recommendations for legislative actions needed	67.7	44
3. Clearer statement of changes since the last FYO	49.2	32
4. Assignment of priorities to needs, problems, and opportunities	41.5	27
5. Better delineation of anticipated social, economic and political impacts or problems	38.5	25
6. Improved presentation format (e.g., more charts, tables, graphics)	21.5	14
7. Less scientific and technical material	16.9	11
8. More specific delineation of relationships between areas, problems, and opportunities	15.4	10
9. Better dissemination to relevant audiences	15.4	10
10. Other (Please describe.):	1.5	1 [2]

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[1] Based on the 65 respondents who were aware of one or more FYO.

[2] The suggestion was: "Keep it short."

Exhibit 7. Would Any of the Following Be a Significant Improvement in Future FYOs? Interviewees' Responses.

	Percentages of Responses 1/				
	Definitely	Perhaps	No	No Opinion	N
1. Five to ten page summary of most significant trends, issues and possible problems or impacts. .	70.5%	16.5%	9.1%	4.0%	176
2. Clearer statements of changes since the last *Five-Year Outlook*.	60.9	17.8	10.3	10.9	174
3. More attention to international implications . . .	45.1	21.7	22.3	10.9	175
4. More emphasis on social and economic costs and problems anticipated from future science or technology developments	40.6	24.6	28.0	6.9	175
5. More attention to policy and legislative implications or actions	40.5	24.9	24.9	9.8	173
6. More delineation of relationships between areas, problems and developments	38.2	25.9	19.4	16.5	170
7. More graphs, tables, charts	32.2	19.9	20.5	27.5	171
8. More emphasis on speculative or controversial forecasts.	22.3	26.3	36.6	14.9	175
9. Less scientific or technical material	8.6	10.9	68.4	12.1	174

1/ Percentages may not add exactly to 100.0 percent due to rounding.

Mr. FUQUA. Thank you very much. We have a vote on the floor and we're going to have to leave and we may have some questions we could submit in writing if that would be permissible.

I want to thank you—Dr. Cort and Dr. Cort—for your compilation of the surveys. I think it's very helpful to us, and Dr. Rettig, I thought you made a very good suggestion that maybe we should pursue in who performs this outlook. I think it's important. I gathered you did mention, maybe, the Congress contract with NAS in the reference that you made, and I think one of the things we must consider is where can we get the broadest perspective and I am not ready to say that we can get that from some of the congressional agencies—like Office of Technology Policy, they do a lot of work and that may be a place to look.

Dr. RETTIG. My general point is that you have a lot of instruments that you control today which didn't exist a few years ago.

Mr. FUQUA. That's correct.

Dr. RETTIG. There would be a learning process on your end as well, but it certainly might serve to sharpen the congressional question asking and I think the general audience's benefit would certainly be served if the congressional audience obtained a better report

Mr. FUQUA. Right.

Mr. Brown, do you have any questions?

Mr. BROWN. No.

Mr. FUQUA. Thank you very much for being here. I apologize for having to break off the hearings as soon as we did. I did have some other questions, but we'll probably submit those in writing and ask you to respond to them.

Dr. RETTIG. Fine, be happy to.

Mr. FUQUA. The committee will stand adjourned.

[Whereupon, at 12:10 p.m., the committee was adjourned, to reconvene subject to the call of the Chair.]

APPENDIX I

BACKGROUND MATERIALS
FOR HEARING ON
"FIVE YEAR OUTLOOK FOR SCIENCE AND TECHNOLOGY" REPORT

January 24, 1984
Committee on Science and Technology
U.S. House of Representatives

compiled by the staff
Committee on Science and Technology
U.S. House of Representatives

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Part 1

STATUTORY REQUIREMENTS

The Five Year Outlook Report was mandated by the Science Policy Act of 1976(Public Law 94-282).

Prescribed Content. The report is to "identify and describe situations and conditions which warrant special attention within the next five years, involving current and emerging problems of national significance that are identified through scientific research, or in which scientific or technical considerations are of major significance; and opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make a significant contribution to the solution of" national problems or to the achievement of Federal program objectives of national goals.

Updating Requirement. The Act originally provided that the Outlook should be revised annually following the submission of the first report in 1977. However, the first three reports were not updatings, but rather contained coverage of different areas of science and technology(See Part 4).

Transfers of Agency Responsibilities. The 1976 Act placed the responsibility for the Five Year Outlook report with the Office of Science and Technology Policy(OSTP) which was established by that Act. In July 1977, at the recommendation of President Carter's OSTP Director Dr. Frank Press, responsibility for the report was transferred, by Reorganization Plan, to the National Science Foundation(NSF). In 1982, with passage of the "Congressional Reports Elimination Act", responsibility for the the Five Year Outlook report was given back to the OSTP.

Merger of Five Year Outlook and Annual Science and Technology Report. In requesting the changes included in the Congressional Reports Elimination Act, the President asked that the Five Year Outlook Report be combined with the Annual Science and Technology Report. This recommendation was accepted by the Congress and incorporated in the Reports Elimination Act. The first combined report was submitted to the Congress in September 1983. The combined report is to be submitted every odd numbered year by January 15th, while, in even numbered years, the National Science Board was mandated to submit a Science and Engineering Indicators report.

The texts of the relevant public laws and reorganization plans appear in the following pages, excerpted to cover the sections dealing with the Five Year Outlook reportand the Science and Technology report.

2

Public Law 94-282
94th Congress, H. R. 10230
May 11, 1976

An Act

To establish a science and technology policy for the United States, to provide for scientific and technological advice and assistance to the President, to provide a comprehensive survey of ways and means for improving the Federal effort in scientific research and information handling, and in the use thereof, to amend the National Science Foundation Act of 1950, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "National Science and Technology Policy, Organization, and Priorities Act of 1976".

TITLE II—OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SHORT TITLE

Sec. 201. This title may be cited as the "Presidential Science and Technology Advisory Organization Act of 1976".

FIVE-YEAR OUTLOOK

42 USC 6615. Sec. 206. (a) Within its first year of operation, the Office shall, to the extent practicable, within the limitations of available knowledge and resources, and with appropriate assistance from the departments and agencies and such consultants and contractors as the Director deems necessary, identify and describe situations and conditions which warrant special attention within the next five years, involving—

(1) current and emerging problems of national significance that are identified through scientific research, or in which scientific or technical considerations are of major significance; and

(2) opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make a significant contribution to the resolution of problems identified under paragraph (1) of this subsection or to the achievement of Federal program objectives or national goals, including those set forth in section 101(b) of this Act.

Annual revision. (b) The Office shall annually revise the five-year outlook developed under subsection (a) of this section so that it takes account of new problems, constraints and opportunities and changing national goals and circumstances, and shall extend the outlook so that it always extends five years into the future.

Consultation. (c) The Director of the Office shall consult as necessary with officials of the departments and agencies having programs and responsibilities relating to the problems, constraints, and opportunities identified under subsections (a) and (b) of this section, in order to—

(1) identify and evaluate alternative actions that might be taken by the Federal Government, State and local governments, or the private sector to deal with such problems, constraints, or opportunities; and

(2) ensure that alternative actions identified under paragraph (1) of this subsection are fully considered by departments and agencies in formulating their budget, program, and legislative proposals.

Consultation. (d) The Director of the Office shall consult as necessary with officials of the Office of Management and Budget and other appropriate elements of the Executive Office of the President to ensure that the problems, constraints, opportunities, and alternative actions identified under subsections (a), (b), and (c) of this section are fully considered in the development of the President's Budgets and legislative programs.

POLICY PLANNING, ANALYSIS, AND ADVICE

42 USC 6614.

SEC. 205. (a) The Office shall serve as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the Federal Government. In carrying out the provisions of this section, the Director shall—

Science and Technology Report.

(2) assist and advise the President in the preparation of the Science and Technology Report, in accordance with section 209 of this Act;

SCIENCE AND TECHNOLOGY REPORT

Transmittal to Congress. 42 USC 6618.

SEC. 209. (a) The President shall transmit annually to the Congress, beginning February 15, 1978, a Science and Technology Report (hereinafter referred to as the "Report") which shall be prepared by the Office, with appropriate assistance from Federal departments and agencies and such consultants and contractors as the Director deems necessary. The report shall draw upon the information prepared by the Director pursuant to section 206 of this Act, and to the extent practicable, within the limitations of available knowledge and resources, discuss such issues as—

(1) a review of developments of national significance in science and technology;

(2) the significant effects of current and projected trends in science and technology on the social, economic, and other requirements of the Nation;

(3) a review and appraisal of selected science- and technology-related programs, policies, and activities of the Federal Government;

(4) an inventory and forecast of critical and emerging national problems the resolution of which might be substantially assisted by the application of science and technology;

(5) the identification and assessment of scientific and technological measures that can contribute to the resolution of such problems, in light of the related social, economic, political, and institutional considerations;

(6) the existing and projected scientific and technological resources, including specialized manpower, that could contribute to the resolution of such problems; and

(7) recommendations for legislation on science- and technology-related programs and policies that will contribute to the resolution of such problems.

(b) In preparing the Report under subsection (a) of this section, the Office shall make maximum use of relevant data available from the National Science Foundation and other Government departments and agencies.

Public document.

(c) The Director shall insure that the Report, in the form approved by the President, is printed and made available as a public document.

BEST COPY AVAILABLE

Executive Office of the President

Message to the Congress Transmitting Reorganization Plan No. 1 of 1977. July 15, 1977

To the Congress of the United States:

I herewith transmit my plan for the Reorganization of the Executive Office of the President (EOP), Reorganization Plan No. 1 of 1977. This plan is the first of a series I intend to submit under the reorganization authority vested in me by the Reorganization Act of 1977 (P.L. 95–17).

It adheres to the purposes set forth in Section 901(a) of the Act.

This plan in conjunction with the other steps I am taking will:

- eliminate seven of the seventeen units now within the EOP and modify the rest. There were 19 units when I took office; the President's Foreign Intelligence Advisory Board and the Economic Policy Board have already been abolished. Thus with this plan I will have eliminated nine of 19 EOP units.
- reduce EOP staffing by about 250 which includes the White House staff reduction of 134 or 28% which I have already ordered.
- improve efficiency by centralizing administrative functions; and
- improve the process by which information is provided for Presidential decisionmaking.

The *Office of Science and Technology Policy* (OSTP) should retain those science, engineering, and technology functions which can be so useful in helping the President and his advisers make decisions about policy and budget issues. Instead of the Intergovernmental Science, Engineering, and Technology Advisory Panels, the President should rely on an intergovernmental relations working group, chaired by the Science Adviser. The Federal Coordinating Council on Science and Technology should operate as a sub-Cabinet working group chaired by the Science Adviser. The reorganization work of the President's Committee on Science and Technology would be part of the overall reorganization effort. The responsibility for preparing certain reports should be transferred to the National Science Foundation.

The proposal places manageable limits on OSTP's broad mandate while emphasizing functions that support the President.

JIMMY CARTER

The White House,
July 15, 1977.

REORGANIZATION PLAN NO. 1 OF 1977

Prepared by the President and transmitted to the Senate and the House of Representatives in Congress assembled, July 15, 1977, pursuant to the provisions of Chapter 9 of Title 5 of the United States Code.

SEC. 5. *Transfers of Functions.*

The following functions shall be transferred:

A. All functions vested in the Director of the Office of Science and Technology Policy and in the Office of Science and Technology Policy pursuant to sections 205(a)(2), 206 and 209 of the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94–282; 90 Stat. 459), are hereby transferred to the President. The Intergovernmental Science, Engineering, and Technology Advisory Panel, the President's Committee on Science and Technology, and the Federal Coordinating Council for Science, Engineering and Technology, established in accordance with the provisions of Titles II, III, and IV of the National Science and Technology Policy, Organization, and Priorities Act of 1976, are hereby abolished, and their functions transferred to the President.

REORGANIZATION PLAN NO. 1 OF 1977, AMENDMENT

RE: EXECUTIVE OFFICE OF THE PRESIDENT

On September 15, President Carter submitted to Congress an amendment to Reorganization Plan No. 1 of 1977, which would alter the make-up of the Executive Office of the President. The text of the President's message and the terms of the amendment follow. 123 Congressional Record H 9638 (H.Doc.No.95–223).

To the Congress of the United States:

I herewith transmit amendments to Reorganization Plan No. 1 of 1977, which I transmitted to you on July 15, 1977. Except as specifically amended hereby, Reorganization Plan No. 1 remains unmodified.

JIMMY CARTER.

SEPTEMBER 15, 1977.

AMENDMENTS TO REORGANIZATION PLAN NO. 1 OF 1977

Prepared by the President and transmitted to the Senate and the House of Representatives in Congress assembled September 14, 1977, pursuant to the provisions of Chapter 9 of Title 5 of the United States Code.

Reorganization Plan No. 1 of 1977, which was transmitted to the Senate and the House of Representatives in Congress assembled on July 15, 1977, is hereby amended as follows:

"Section 6. Transfers of functions.

"The following functions shall be transferred:

"A. All functions vested in the Director of the Office of Science and Technology Policy and in the Office of Science and Technology Policy pursuant to sections 205(a)(1), 206 and 209 of the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94–282; 90 Stat. 459), are hereby transferred to the Director of the National Science Foundation. The Intergovernmental Science, Engineering, and Technology Advisory Panel, the President's Committee on Science and Technology, and the Federal Coordinating Council for Science, Engineering and Technology, established in accordance with the provisions of Titles II, III, IV of the National Science and Technology Policy, Organization, and Priorities Act of 1976, are hereby abolished, and their functions transferred to the President.

"Section 7. Effective date.—This Reorganization Plan shall become effective at such time or times on or before April 1, 1978, as the President shall specify, but not sooner than the earliest time allowable under Section 906 of Title 5 of the United States Code."

Public Law 97-375
97th Congress

An Act

To discontinue or amend certain requirements for agency reports to Congress.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Congressional Reports Elimination Act of 1982".

REPORT BY THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SEC. 215. The National Science and Technology Policy, Organization, and Priorities Act of 1976 (42 U.S.C. 6601, et seq.; Public Law 94-282) is amended as follows:

(1) section 209 is deleted; and

(2) in section 205(a)(11), strike out "section 209" and insert in lieu thereof "section 206";

(3) section 206 is amended to read as follows:

"SCIENCE AND TECHNOLOGY REPORT AND OUTLOOK

"SEC. 206. (a) Notwithstanding the provisions of Reorganization Plan Number 1 of 1977, the Director shall render to the President for submission to the Congress no later than January 15 of each odd numbered year, a science and technology report and outlook (hereinafter referred to as the 'report') which shall be prepared under the guidance of the Office and with the cooperation of the Director of the National Science Foundation, with appropriate assistance from other Federal departments and agencies as the Office or the Director of the National Science Foundation deems necessary. The report shall include—

"(1) a statement of the President's current policy for the maintenance of the Nation's leadership in science and technology;

"(2) a review of developments of national significance in science and technology;

"(3) a description of major Federal decisions and actions related to science and technology that have occurred since the previous such report;

"(4) a discussion of currently important national issues in which scientific or technical considerations are of major significance;

"(5) a forecast of emerging issues of national significance resulting from, or identified through, scientific research or in which scientific or technical considerations are of major importance; and

"(6) a discussion of opportunities for, and constraints on, the use of new and existing scientific and technological information, capabilities, and resources, including manpower resources, to make significant contributions to the achievement of Federal program objectives and national goals.

"(b) The Office shall insure that the report, in the form approved by the President, is printed and made available as a public document."; and

(4) in section 205(a)(11), insert "and the Congress" after "President".

Part 2

COSTS OF THE OUTLOOK REPORTS

In support of the preparation of each of the Five Year Outlook reports OSTP and NSF have commissioned in-depth studies from individuals and groups outside government, most notably the National Academy of Sciences. This has led to questions about the costs of preporing the Five Year Outlook Report.

The total cost of preparing the reports involve a) the time of government employees working on the report, and b) the costs of grants and contracts for the associated studies. The time of the civil service employees involved can only be roughly estimated. In the case of the NSF staff it amounts to approximately $135,000 for each of the first two reports. In addition, government employees at OSTP and at other agencies were involved. However, such other government employees were mainly involved in the preparation in the first two reports, and much less in the third. A conservative estimate, therefore, is that under the current mode of operation roughly $150,000 was spent in-house by the government in preparing the first two reports, and approximately $35,000 in preparing the third report.

For each of the 3 Outlook submitted to date a major study was performed by the National Academy of Sciences. In addition, qualified individuals and organizations with expertise in particular fields have been commissioned to provide issue papers on particular issues. The performance of such supportive studies is in accord with the Science Policy Act's provision to utilize "appropriate assistance from ... such consultants and contractors" as is deemed necessary.

A statement of the contract and grant cost elements involved in the preparation of each report has been supplied by the NSF and appears on the following pages(pp.). Based on that statement and the discussion above of government in-house costs, the total cost of the three Outlook reports submitted to the Congress to date is estimated to be:

First Five Year Outlook	
Academy Study	$344,200
Other Costs	279,150
Total	623,350
Second Five Year Outlook	
Academy Study	$377,500
Other Costs	478,100
Total	855,600
Third Five Year Outlook	
Academy Study	$110,000
Other Costs	43,200
Total	153,200

Summary of First *Five-Year Outlook* (1980)*

1.	Contract with National Academy of Sciences	$344,200
2.	28 small contractors for paper writing & editing**	103,650
3.	Printing costs (2,000 copies/2 volumes)	25,500
	TOTAL	$473,350

Summary of Second *Five-Year Outlook* (1981)

1.	Contract with National Academy of Sciences	$377,500
2.	Contract with American Association for the Advancement of Science	185,780
3.	Contract with Social Science Research Council	119,943
4.	Contract for editorial assistance	2,000
5.	Printing costs (4,000 copies/3 volumes)	20,401
	TOTAL	$705,624

Summary of Third *Five-Year Outlook* (1982)

1.	Contract with National Academy of Sciences	$110,000
2.	Printing costs (3,500 copies/1 volume)	8,200
	TOTAL	$118,200

Evaluation Contractors

1.	Five individual evaluations of first *Outlook****	$ 44,566
2.	Four individual evaluations of second *Outlook****	68,743
3.	Contract for survey of utilization of all *Outlooks****	51,431

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* Costs are the best available figures based on a search of the files.
** Names of paper contractors listed below.
*** Names of evaluation and survey contractors listed below.

NSF Staffing

It is difficult to pin down NSF staff involvement in these reports with precision because the tasks for each report varied, and because internal NSF organizational responsibilities changed over time. Nevertheless, a reasonable estimate of the "average" staff efforts connected with each report would be as follows:

1 - FT GS-15 writer and coordinator

1 - FT GS-14 project manager

1 - FT GS-11 research assistant and editor

1 - FT GS-7 secretary

In addition to NSF staff, there was significant staff involvement from other Federal agencies in the preparation of their contributions to the first two Outlooks. Twenty-one agencies contributed to the 1980 Outlook, and 23 to the 1981 version.

Part 3

TIME AND FREQUENCY OF SUBMISSION

The time and frequency of submission of the Outlook report has been irregular, and this may have contributed to some extent to the relatively low level of attention given to the report.

The time and frequency of submission should be governed in part by the statutory requirements which, in turn, have been established chiefly to meet the needs of the Congress. It appears to have been governed in the past mainly by the completion time of the external studies and the writing and review process within the Executive Branch.

The statutory requirements as initially established by the 1976 Science Policy Act, called for the submission of the first Outlook "within the first year of operation" of the OSTP, and for annual revisions thereafter. The first OSTP Director, Dr. H. Guyford Stever, was sworn in on August 12, 1976, but the first Outlook report was not submitted to the Congress until May 1980. The submission of the three reports provided so far under the 1976 Act have been as follows:

	Title of Report	Date of NSF Director's Transmittal Letter
1st Report	The Five Year Outlook: Problems, Opportunities, and Constraints in Science and Technology	May 12, 1980
2nd Report	The 5-Year Outlook on Science and Technology, 1981	Jan 26, 1982
3rd Report	The Five-Year Outlook on Science and Technology, 1982	Sep 15, 1983

When the Congressional Reports Elimination Act was signed into law in December 1982, the Five Year Outlook Report were combined into one report due on January 15th of each odd numbered year. The Congressional intent in mandating the January 15th date was to make the report available shortly before the submission of the budget, so that its content could be reviewed and discussed in conjunction with the posture and budget authorization hearings held in January and February.

The first combined report was submitted by the OSTP Director to the President in September 1983 and by the President to the Congress on October 3rd 1983(The Science Indicators report which was due on January 15th in even numbered years, is expected before the end of January 1984).

For reference and comparison the annual Science and Technology reports have in past years been submitted as follows:

Number of Annual S & T Report	Date of Submission
1st	Sep 27, 1978
2nd	Nov 12, 1980
3rd	Jan 19, 1981
4th	Apr 21, 1982

The Science Indicators reports have in recent years reached the Congress on the following dates:

Year of Science Indicators Report	Date of Submission
SI 1974	Feb 23, 1976
SI 1976	Jan 23, 1978
SI 1978	Nov 20, 1979
SI 1980	Dec 16, 1981
SI 1982	due Jan 15, 1984

Part 4

THE NSF FIVE YEAR OUTLOOK REPORTS

During the period when responsibility for the Five Year Outlook report was with the NSF(Sep 1977 to Dec 1982), three reports were developed and submitted to the Congress.

Length of Reports. The initial reports submitted to the Congress were voluminous as indicated by the following table showing the number of volumes and pages of each report:

	volumes		pages
First Report	vol. I		113
	vol. II		672
		total	785
Second Report	summary vol.		87
	source mat'ls, vol.1		385
	source mat'ls, vol.2		469
		total	941
Third Report	one vol.	total	95

Use of Academy Report. All three reports reprinted the full text of the Academy of Sciences report. In the first and second report was included in a "Source Materials" volume. In the third report the Academy study constituted, with minor, editorial changes, the report itself, and a disclaimer was included on the title page of the report stating that "the views and opinions expressed herein do not necessarily reflect the policies of the National Science Foundation".

Letter of Transmittal. Each report includes a brief, one-page Letter of Transmittal to the Congress by the NSF Director. In addition, the first report included a longer statement by the NSF Director in which he gives his personal view of the six most important emerging issues. The subsequent reports have no comparable issue statement.

In order to convey the content and thrust of each of the reports the table of contents and a small portion of the text is reproduced in the remainder of this part.

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FIRST NSF OUTLOOK REPORT

the Five-Year Outlook:

Problems, Opportunities and Constraints in Science and Technology

volume I

National Science Foundation

LETTER OF TRANSMITTAL

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

OFFICE OF THE
DIRECTOR

MAY 12, 1980

To the President and Members of Congress:

I am pleased to submit the first *Five-Year Outlook* on science and technology as required by the National Science and Technology Policy, Organization and Priorities Act of 1976.

In addition to materials written and compiled by the staff of the National Science Foundation, I have prepared a personal statement reviewing several important opportunities for science and technology to contribute to the solution of major national issues. All these issues involve public policy choices that will have to be made within the next five years and which deserve wide discussion. I believe this *Five-Year Outlook* can help facilitate such discussions in the Executive Branch, the Congress and throughout the Nation.

Respectfully,

R. C. Atkinson

RICHARD C. ATKINSON
Director

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Statement of the Director of The National Science Foundation

The first effort to prepare a *Five-Year Outlook* on science and technology has been a considerable challenge. The object was to capture perspectives, not to produce a catalog. The idea was to look *ahead*, not backward. Though the glimpse of the future was defined to be a five-year period, the processes of research and development hardly obey such discipline. The temporal constraint, therefore, had to take the form of relating the agenda of science and technology to the visible near-term problems of American society and its external responsibilities for stable peace and the improvement of the human condition. This task was not amenable to ivory tower meditation. It required wide participation, and we have gained a great deal by calling upon the National Academy of Sciences, government agencies, and thoughtful individuals.

The National Science Foundation's synthesis of these contributions to the *Five-Year Outlook* comprises the core of Volume I; the contributions themselves constitute Volume II. The individual contributions reflect the vigor and excitement of American science and technology, and illustrate the wide-ranging contributions that science and technology can make to the solution of problems faced by this Nation. While we all recognize that science and technology cannot provide a panacea for those problems, they do offer an impressive range of opportunities.

In this statement, which constitutes my personal overview of the *Five-Year Outlook*, I want to concentrate on six issues. These issues are discussed at greater length in the *Five-Year Outlook* and, in my judgment, warrant the special attention of the Executive and Legislative branches of the United States Government and of the American people:

1. Stimulating innovation and productivity in industry and agriculture.
2. Ensuring adequate supplies of energy and nonrenewable resources.
3. Improving the science and technology base for risk assessment.
4. Contributing to improvements in health.
5. Maintaining international leadership in science and technology.

The sixth issue undergirds these five:

6. Ensuring the continued vitality of the Nation's scientific and technological enterprise.

These issues will persist in some form well beyond the period of this *Five-Year Outlook*. All of them involve public choices that will have to be made within the next five years, and which deserve discussion throughout the Nation.

1. STIMULATING INNOVATIONS AND PRODUCTIVITY IN INDUSTRY AND AGRICULTURE

The declining rate of productivity growth in some industrial sectors is an important factor in the reduced economic progress of the United States. Productivity, in turn, depends in substantial measure on industrial innovations—the development and commercialization of new products and processes, and the improvement in the efficiencies of existing processes. As the recent Domestic Policy Review on Industrial Innovation clearly recognized, innovation is also an important factor in reducing inflation, assuring the availability of adequate supplies of energy, maintaining the Nation's international competitive position, and improving the quality of all of our lives.

The Domestic Policy Review announced new Federal initiatives in nine critical areas. Several of these initiatives provide opportunities for science and technology to spur industrial innovation and deserve continued attention during the next five years:

- Augmenting research on generic technologies that underlie several industries.
- Expanding cooperative programs of research between industry and and universities.
- Increasing incentives to small businesses and large industries to undertake high-risk research.
- Refining the scientific basis of the regulatory system.
- Strengthening the patent system and clarifying anti-trust policy on collaboration in research and development.
- Helping labor and management adjust to technical change.
- Enhancing the dissemination of information to industry.

In agriculture, high productivity is essential to sustain domestic food supplies, to feed people in other countries, and to contribute to the Nation's balance of trade. Interest in using renewable resources for energy production and as substitutes for petroleum-based industrial chemicals is providing new challenges to American agriculture.

Factors that threaten agricultural productivity are rising costs of fuels and petroleum-based fertilizers, environmental restrictions on pesticide use, growing competition for water by new synthetic fuel industries (particularly in the semi-arid regions of the West), and effects of water and air pollution on crops. Since these factors will certainly persist into the next century, research should focus on the following long-range opportunities:

- Expanding fundamental knowledge of biological processes (such as photosynthesis, the relationship between photosynthesis and nitrogen fixation, carbon dioxide fixation, and the dynamics of cell membranes) needed to develop food plants that require less fertilizer and fresh water and are more resistant to inhospitable environments.
- Developing environmentally safe methods for controlling animal and plant pests and diseases.
- Augmenting knowledge of the effects of air pollution (particularly acid rain) on agricultural crops.
- Applying solar and biomass energy sources to reduce agriculture's dependence on fossil fuels.
- Using more effectively satellite data on atmospheric, oceanic, and land-surface dynamics to improve long-range agricultural management.

2. ENSURING ADEQUATE SUPPLIES OF ENERGY AND NONRENEWABLE RESOURCES

This Nation's industrial growth has been based on the ready availability of low-cost energy and other material resources. Worldwide shortages of petroleum will become increasingly severe during the remainder of the century. We need research to help achieve two urgent national goals: First, to reduce our dependence on foreign and diminishing domestic sources by conservation and substitution. Second, to develop environmentally safe alternative sources.

The ability of science and technology to help meet these goals will be influenced by policy decisions made during the next five years. For example:

- Additional petroleum sources need to be identified and evaluated. Research by government and industry to establish a scientific framework for the development of the ocean margins for that purpose should be intensified.
- The science and technology base for the synthetic fuel industry must be augmented quickly to assure that these fuels are available to provide a substantial part of the Nation's energy in the 1990s.
- We must improve the safety of conventional nu-

clear power plants, and pay greater attention to the role of human factors in the operation of the plants. We must also resolve radioactive waste disposal problems to retain for the Nation the option of nuclear fission as a source of energy.

- If advanced energy technologies (including nuclear fusion, photochemical fuels production from solar energy, and direct solar conversion) are to become the primary energy source during the 21st century, we must emphasize at once research that will provide the scientific knowledge for their development and commercialization.
- The ability to estimate uranium resources has been called into question by recent re-evaluations. It is important that geologists and geochemists develop improved techniques for estimating uranium deposits and a wide range of other mineral resources. Independent of estimated resources, we must begin immediately to design the next generation of reactors to be more uranium-efficient in order to extend the useful life of known deposits.

Petroleum is far more valuable as the basis for organic industrial products (including fertilizers, plastics and pharmaceuticals) than as a fuel. Rising petroleum prices will affect the costs and availability of these products. Foreign supplies of other organic raw materials essential to our economy, most notably rubber, could also be seriously disrupted. Thus, industrial use of domestic renewable resources should be pursued as a long-range option. Promising opportunities for the next five years include research on the feasibility of:

- Using domestic plants as sources of organic materials. For example, guayule, a plant native to the arid lands of the Southwest, could provide an alternative to imported rubber, and jojoba, a plant that thrives in the same region, could become a source of lubricating oil.
- Extracting chemical feedstocks and petrochemical substitutes from coal and lignocellulosic materials (such as non-commercial species of trees, underutilized hardwoods, and lumber industry residues). The use of genetic techniques to produce microorganisms capable of converting these raw materials into useful chemicals is a particularly attractive possibility.

Expert opinions differ about the timing and impact on the American economy of world shortages of industrially important metals. Disruptions in the supply of some metals such as chromium have been experienced and are likely to recur with increasing frequency. Prices of others, such as copper, will rise as the richest and most accessible sources are depleted. National security considerations argue strongly against overdependence on a small number of politically unstable foreign sources for such primary resources. Promising opportunities related to the supply and use of essential metals that can be pursued during the next five years are:

- Using remote-sensing satellites and deep-probing radar to identify new mineral deposits and evaluate known deposits.
- Implementing technologies for improved extraction of metals from ores, sea water, and the ocean floor.
- Expanding research on the properties of materials, as a basis for substitution and new energy-efficient applications. For example, the replacement of metals and alloys with silicon ceramics in energy-conversion devices would permit higher operating temperatures and greater energy efficiencies.
- Pursuing research on the fundamental physical and chemical bases of corrosion, fracture and wear, thereby improving the durability and recycling potential of scarce materials.

3. IMPROVING THE SCIENCE AND TECHOLOGY BASE FOR RISK ASSESSMENT

Science and technology often are critical in the identification of policy issues, in making decisions about environmental standards, and in assessing the risks of new technologies. If regulations are to become more rational, we must expand the science on which these regulations are based. Assessing a risk (whether to health, safety, or the environment) is a task combining both facts and values. The task is complicated by differing opinions of how much risk is acceptable for a particular level of benefit. It is usually possible to reduce the hazards associated with a given technology by spending enough money. It is also possible to eliminate the hazard completely by eliminating the technology. But the long-term social costs of foreclosing promising technological options by needlessly stringent environmental regulations are too easily overlooked.

More research is needed to understand the causal mechanisms underlying various risks and to implement appropriate control technologies. Ultimately society must determine the risks that individuals and groups should accept in exchange for the benefits of a given technology. But in the absence of better information about the effects of specific hazards, the governmental decision process cannot function effectively.

During the next five years there is an urgent need to determine the true range of effects of a large variety of hazards; to refine methods to detect and measure those effects; and to assess the economic and social impact of various risk-mitigation options. In particular:

- Many substances may pose risks to human beings and their descendents only at high levels of exposure. However, it may sometimes be prudent to assume, in the absence of evidence to the contrary, that any level of exposure presents some risk. Unfortunately, the costs of technologies to decrease the concentration of a contaminant in food or in the environment increase as the concentration decreases, often sharply so. Epidemiological studies provide the only direct means for assessing the effects of low-level exposure to chemicals and radiations; although these studies are expensive and involve evaluation over extended time periods, a balanced regulatory policy requires that they be actively pursued.

- Some toxic substances may produce adverse effects even in minute amounts. The development of analytical techniques for the rapid detection of such such substances (permitting surveys to establish baselines and monitor changing levels) should be encouraged.

- Other substances may not be harmful except over long time periods or to future generations. Such effects can only be evaluated when underlying causal mechanisms are understood, and this requires fundamental research.

- Failure to recognize and take steps to mitigate hazards can entail serious risks; on the other hand, excessive conservatism in reducing such risks may entail social and economic costs that are not immediately obvious. An important priority is to improve analytical techniques to assess and compare the full range of costs, risks and benefits of specific regulations.

- If the political process is to operate effectively and fairly in setting acceptable levels of risk, then the public must be better informed about the complicated tradeoffs between risk mitigation and social benefit. High priority should be given to developing ways of facilitating knowledgeable public discussion about the regulatory process.

4. CONTRIBUTING TO IMPROVEMENTS IN HEALTH

Equitable access to high-quality health care for all Americans will receive considerable attention during the next five years. Many regard good health for everyone as an obtainable ideal, and this provides a striking example of the way science can change expectations. Scientific research has contributed to improvements in nutrition and sanitation, both of which are important determinants of health. Science has contributed to the control or elimination of many infectious diseases that were once widespread (such as smallpox, tuberculosis, pneumonia and polio).

As a result of these developments, the longevity of Americans has been augmented markedly during this century. But this has, in turn, magnified the seriousness of noninfectious diseases common to middle and old age, such as heart disease and cancer. These and other disorders (including arteriosclerosis, hypertension, and mental illness) are linked in part to environmental factors, and in part to lifestyle factors over which individuals have control.

Science and technology can contribute to better health by advancing our understanding of fundamental biological processes in health and disease; by expanding our knowledge of the effects of lifestyles on health; by enhancing the effectiveness of medical interventions; and by supporting improvements in public health and the delivery of health services. Specific opportunities include:

- Using recombinant DNA techniques to advance our understanding of genetics at the molecular level (thereby offering the possibility of detecting and correcting genetic diseases), and to produce essential pharmaceuticals, such as insulin and interferon, at lower costs and higher purities.
- Expanding our understanding of genetic and behavioral determinants of cardiovascular diseases, particularly hypertension and arteriosclerosis.
- Pursuing research on brain chemistry at the molecular level to increase our understanding of such problems as obesity, schizophrenia, depression, and mental retardation.
- Augmenting our knowledge of psychological and social determinants of alcohol and drug abuse, cigarette smoking, and other habits that adversely affect health and longevity.
- Increasing public understanding of the relationship between lifestyle, behavior and disease so that individuals will have a deeper appreciation

of ways to maintain and improve their own health.

5. MAINTAINING INTERNATIONAL LEADERSHIP IN SCIENCE AND TECHNOLOGY

It is imperative that the Nation recognize the vital role that science and technology now play in international affairs. The international dimensions of energy, environment, food, and oceanic exploration are evident. Several industrialized nations have developed scientific capabilities that now approach our own. The lesser developed countries are seeking a larger share of the scientific and technological capabilities that are overwhelmingly concentrated in the industrialized countries.

The Nation's declining advantage in technology needs to be discussed widely and brought into focus. At the same time, the scientific credentials of other countries provide opportunities for bilateral and multilateral research projects. Examples of scientific activities from which the United States benefits by pooling its resources with other countries include:

- Participation in the Global Atmospheric Research Program which includes, among its objectives, better monitoring of the global climate and assessing climatic changes due to human activities (e.g., increased burning of fossil fuels).
- Collaborative research with Japan on nuclear fusion, photosynthesis, and synthetic fuel production.
- Collaboration with the People's Republic of China on earthquake prediction and earthquake damage mitigation.
- Cooperation with Mexico on research on the arid lands on both sides of the border, with emphasis on developing new crops and making effective use of scarce water resources.

Scientific cooperation with the lesser developed countries often requires a different approach than with industrialized countries—in part because our priorities for research may differ from theirs. Two examples illustrate the problems:

- The U.N. Law of the Sea Conference has yet to resolve issues relating to the control of ocean minerals or the question of free access to the oceans for scientific purposes.
- Demands by less developed countries for portions of the radio frequency spectrum for communications challenge the exclusive use of parts of the spectrum for research and other scientific purposes.

Opportunities to facilitate the transfer of science and technology to the less developed countries exist in several areas. In many cases such transfers can yield results of direct value to the United States. For example:

- Assisting less developed countries in planning for their future energy needs with due regard for conserving their own resources and minimizing adverse effects on the global environment.
- Developing more efficient ways to use agricultural wastes and nonfood crops as fuels and as substitutes for petroleum-based products.
- Improving technologies for locating and exploiting underground water resources and for desalting sea water.
- Pursuing collaborative research on the causes of desertification and deforestation and developing methods for returning land to productive uses.

6. ENSURING THE VITALITY OF THE NATION'S SCIENTIFIC AND TECHNOLOGICAL ENTERPRISE

Advances will be made in understanding and dealing with the problems identified in this *Five-Year Outlook*, in part because a firm scientific base has been established by past investments in research. But these problems will concern the Nation in some form for years to come. There is an understandable temptation to allocate resources to immediate and pressing problems at the expense of investments in longer term scientific and technological capabilities. However, if the Nation is to maintain its ability to face the future, it must deal with the problems that now confront its research institutions.

Specific needs and opportunities during the next five years are as follows:

- The recent Domestic Policy Review on Industrial Innovation stressed the desirability of cooperation between the public and private sectors to enhance the technical knowledge base in areas of interest to industry. Cooperative development of two classes of technologies deserves special emphasis: (1) generic technologies that underlie several industries, and (2) technologies required for compliance with environmental, health and safety regulations.

- Expanded university-industry cooperation will stimulate and enhance university research and make the results of research more accessible to industry. By providing opportunities for linkages among scientists and engineers in both sectors, cooperative projects will facilitate institutional arrangements whose significance transcends the value of any particular project.

- Problems created by the obsolescence of instrumentation and the increasing costs of new and more sophisticated scientific apparatus must be alleviated. These problems are particularly severe for university laboratories, but they also exist in industry. Regional instrumentation centers available to qualified scientists can provide a partial response to the problem, as well as greater attention to pooling equipment funds and sharing apparatus.

- The financial problems faced by universities cannot be resolved by the Federal Government. However, the government can help the universities remain viable research institutions by continuing to support high-quality research, and by reducing the costs of compliance with complicated Federal regulations, particularly those that do not take into account the special nature of universities.

- Decreasing university enrollments have caused a decline (as well as an age imbalance) in the faculties of many science departments. As a result, tenure positions for promising young scientists are, and will continue to be, scarce in several fields. This situation is likely to persist well into the 1990s. New opportunities must be found for young scientists to pursue careers in universities so that these institutions can continue to play a vital role in the Nation's science programs.

- Research opportunities in industry are increasing, and there is a growing need for scientists and engineers at all levels of government. Thus, messages about limited numbers of university faculty positions should not discourage young people from careers in science and technology. On the contrary, since the strength of the Nation depends strongly on the availability of highly motivated scientists, the flow of young people into science must be encouraged.

- More attention needs to be paid to technological innovations as an aid to instruction, and ways must be found to make teaching apparatus accessible to schools, colleges and universities. For example, computers can be used to tailor instruction to the needs of individual students, and provide students with on-line experience in problem solving.

SCIENCE AND TECHNOLOGY IN THE NATION'S FUTURE

The contributions of long-term research to the solution of national problems are illustrated by many examples in this *Five-Year Outlook*. But these examples focus on problem areas that have already been identified. In that respect they fail to convey the total contribution research makes to our society. In addition to research with clear applications, we need to strengthen the context in which scientific activities are pursued and to encourage research that has no identifiable applications. Polio vaccine, the laser, transistors, and integrated circuits were not realized because someone tried to solve a practical problem. Rather, they were the result of research carried out by well-trained and highly motivated scientists whose primary goal was a better understanding of nature. There can be no question that research underway now—with no identifiable applications—will in time lead to significant new developments.

Whether or not a particular research project has an identifiable application, the fact that it seeks an answer to a scientific question is a contribution in its own right. Splendid opportunities for advancing our understanding of problems that have long challenged the human intellect are described in this *Five-Year Outlook*. These opportunities, no less than those associated with specific societal problems, deserve attention and support.

This is the first *Five-Year Outlook* on science and technology prepared in response to the National Science and Technology Policy, Organization and Priorities Act of 1976. However, it is but one in a succession of government reports calling attention to the role of science and technology in dealing with national issues. One of the most important reports was written thirty-five years ago under the leadership of Vannevar Bush, the Director of the Office of Scientific Research and Development during World War II. The Bush report, entitled *Science—The Endless Frontier*, responded to a request by President Franklin D. Roosevelt to examine how the Federal Government and American science might cooperate in peacetime to "create a fuller and more fruitful employment and a fuller and more fruitful life." The report assessed the contributions that science and technology could make in the postwar years, and prepared a plan to marshal the Nation's resources to that end. Significantly, it focused on the need to make long-term public investments in scientific research.

The wisdom inherent in the Nation's acceptance of the Bush report's recommendations on long-term research is amply illustrated in this *Five-Year Outlook*. In this regard Dr. Bush's admonition deserves reemphasis:

> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world.

The Bush report was an assessment of national problems and a specific plan to mobilize science in the Nation's service. But it was more than that. Invoking a metaphor of the American West, it called on the Nation to join science in exploring the frontiers of the mind and spirit. The concerns and enthusiasms of American scientists and engineers reflected in this *Five-Year Outlook* convince me that the metaphor of an endless frontier is still very real. Finding more effective ways to use science and technology is among the most important challenges the Nation faces in the next five years.

Richard C. Atkinson

Introduction

CONTEXT OF THIS FIVE-YEAR OUTLOOK

With the passage of the National Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94-282), the United States Congress legislatively expressed its belief in "the profound impact of science and technology on society, and the interrelations of scientific, technological, economic, social, political and institutional factors."

As one means of developing a better understanding of the effects of science, technology and society on one another, the Act required that a *Five-Year Outlook* be prepared periodically to "identify and describe situations and conditions which warrant special attention within the next five years, involving—

> "(1) current and emerging problems of national significance that are identified through scientific research, or in which scientific or technical considerations are of major significance; and
>
> "(2) opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make a significant contribution to the resolution of problems identified under paragraph (1) of this subsection or to the achievement of Federal program objectives or national goals, including those set forth in section 101(b) of this Act."

The goals set forth in Section 101(b) are generally concerned with advances—domestic and international, intellectual and material, personal and social—to which American science and technology can contribute.

Although this is the first *Five-Year Outlook* on science and technology to be prepared in response to this specific congressional directive, it is not the first time an agency of the United States Government has been asked to assess future opportunities and problems associated with the effects of science on issues of national concern. One notable precursor was *Science—The Endless Frontier*, written in 1945 by a task force headed by Dr. Vannevar Bush, Director of the Office of Scientific Research and Development during World War II, in response to a request from President Franklin D. Roosevelt for specific recommendations on how the scientific capabilities of the Nation could be used most effectively in peacetime to "create a fuller and more fruitful employment and a fuller and more fruitful life."[1]

The Bush report argued that since science had become essential to the national welfare, it had also become the proper concern of government. It recommended that the U.S. Government expand and improve its own research laboratories, encourage industrial research by changes in tax and patent laws, and offer fellowship opportunities to assure a steady supply of talented, well-trained scientists. Its most emphatic and, at the time, most original recommendation was that the Federal Government should provide strong support for the conduct of basic research in the universities as the most effective means of assuring that the country would maintain an adequate knowledge base to draw upon to aid in resolving problems that it would inevitably confront in the future.

A comparison of the changes that have occurred in the size and character of American science and technology from World War II until the late 1960s, and from the late 1960s through 1979, provide a useful context for this *Five-Year Outlook*.

The Bush report states that in 1940, the last full year before the United States entered the war, American universities awarded slightly more than 1,600 PhD's in the mathematical, physical and life sciences.[2] By 1965 the number of PhD's awarded in those fields in the United States had risen to approximately 6,000.[3] In that same year a total of 10,500 PhD's were awarded in all fields of the natural and social sciences and engineering. Three years later that number was well over 14,000. In 1965 slightly fewer than 500,000 full-time equivalent scientists and engineers were employed in research and development in the United States. Three years later their number was about 550,000.

In 1940, according to the Bush report, expenditures for scientific research by the U.S. Government, by industry and by the universities were $69 million, $240 million and $31 million, respectively, totalling $300 million.[4] In 1965 total research expenditures in the United States had risen to $6.89 billion and by 1968 to $8.44 billion, with the U.S. Government's contribution being approximately twice that of the private sector. In 1965, total university expenditures for basic research were $1.14 billion, with the bulk of these funds derived from the Federal Government. By 1968 university basic research expenditures had risen to $1.65 billion, representing a 23 percent constant dollar increase over that three-year period.[5]

Clearly, the Bush report's general recommendations were at least consistent with, and were probably a principal stimulus of, the spectacular growth of the American scientific enterprise during the first two post-war decades. But that growth rate did not persist. The number of PhD's awarded in the mathematical, physical and life sciences rose to almost 10,000 in 1970, but by 1977 (the last year for which numbers are available) had declined to 8,600, which was roughly the 1968 level. Approximately 17,400 PhD's were awarded by American universities in all science and engineering fields in 1977, with the social sciences accounting for the major portion of the increase as compared with 1968. Total full-time equivalent numbers for all scientists and engineers working in R&D barely increased from about 550,000 in 1968 to about 570,000 in 1977. Their number was estimated to have risen to 610,000 by 1979.[6]

In 197[illegible] total national research expendi[illegible] current dollars, were $15.32 billion, compared [illegible] 8.44 billion in 1968. However, constant dollar expenditures for these two years did not differ appreciably. Indeed, the 1977 level represents a recovery from a decline in constant dollar expenditures that began in 1969 and continued through 1975. Total national constant dollar expenditures for research and development and for basic research conducted in the universities also declined markedly during the early 1970s. However, by 1977 both had again risen to approximately their 1968 levels.

The situation has continued to improve. In 1979, total national expenditures for all research and for research and development (measured in constant dollars) were about 8 percent above their 1977 levels. By 1979, private industry's contribution to total national research expenditures was almost two-thirds that of the U.S. Government, while industry's research and development expenditures approached equality with the government's. Constant dollar expenditures for all basic research increased by more than 14 percent, and for basic research conducted by universities they increased by almost 16 percent. These latter increases reflect explicit decisions by the Carter Administration to make basic research a high priority item in each of its budgets.[7]

The leveling off of national expenditures for research and development which began in the late 1960s and persisted throughout most of the 1970s can be attributed largely to economic and demographic factors. The decline of Federal investments in research during the latter years of the war in Vietnam was particularly striking. It is also worth observing that the sharply different growth trends from World War II to the late 1960s and from the late 1960s to the present are paralleled by changes in the national mood. The Bush report was written during the final months of a war that seemed, to many, to establish both undisputed world leadership for the United States and a new unity of purpose among its citizens. Science and technology had been central to what President Roosevelt called the "vision, boldness, and drive" with which the war had been waged.[8] The "endless frontier" metaphor seemed entirely appropriate in 1945, for there appeared to be virtually no limit to what science and technology could accomplish for the United States, or what the United States could accomplish both for itself and for the world.

By the mid-1960s that sense of national unity and purpose had been dampened. Serious doubts were being expressed about the tacit assumption that economic growth was in and of itself an undisputed good. Science and technology, as major contributors to growth, were being implicated in some quarters as major contributors to the adverse *effects* of growth. The war in Vietnam placed heavy pressures on the controllable parts of the Federal budget. And scientists and engineers themselves were beginning to see more clearly the wisdom inherent in the Bush report's warning that "Science, by itself, provides no panacea for individual, social and economic ills."[9]

President Carter's budget requests and his March 27, 1979, science and technology message to the Congress have demonstrated his strong commitment to scientific research. Recent annual increases in total Federal support for research and for basic research conducted by universities, measured in current dollars, have been at least as high as they were during the early 1960s. Unfortunately, continuing high inflation rates have resulted in a diminution of increases in constant dollar terms. However, the opportunities to advance knowledge and understanding over a wide range of scientific disciplines are in no way diminished. The metaphor of the endless frontier of the mind and spirit persists for most of those directly engaged in scientific research. Among scientists and engineers, only a few here and there perceive internal limits to the potential achievements and benefits of science and technology.

The non-scientist public, for its part, seems to have adopted an attitude of watchful expectation toward science and technology. Opinion polls indicate that a clear majority of Americans remain supportive.[39] But probably few believe, if they ever did, that science and technology offer unique or easy solutions to problems of individual and social concern. Many are prepared to believe that science and technology still hold great promise for the Nation. But many also want to know exactly how science and technology can be brought to bear on problems of national interest, and what the economic and social costs and benefits of various feasible options will be.

The Carter Administration's strong commitment to research offers considerable hope that the period of increasing investments will continue into the 1980s. Hence, the present is an especially opportune time to assess the potential of American science and technology to provide insights and tools to contribute to the diagnosis and solution of the many problems the Nation will face during the first half of the 1980s.

HOW PREDICTABLE ARE SCIENCE AND TECHNOLOGY?

Several questions arise in any attempt to assess future problems and opportunities for science and technology and their future impacts on national policy concerns. Perhaps the most difficult of these has to do with the different time scales of science (particularly basic research), technology and the legislative process.

Basic research is a quest for new knowledge about questions that have been posed in a general way since antiquity: What is the nature of matter and of the universe? What is the nature of life? What is the nature of human society? Data are acquired, and cause-and-effect relationships are sought among those data. Occasionally, recognition of a certain causal pattern leads to a profound new insight which points an entire discipline in a new direction (or even establishes a new discipline) and necessitates a new program of data collection and the search for new patterns. It is not too difficult to predict the *minimum* level of progress that a field of basic research will achieve in five years, at a particular level of support: one simply assumes that data will be acquired at a rate limited only by resources. *But there is no way to predict if, when, or whether a fruitful new pattern may be recognized to upset the conservative predictions.* By the same token it is almost impossible to predict anything about a particular subfield of basic research twenty years from now. For unless a line of inquiry yields useful insights within that time limit, the inquiry will probably be altered significantly, and may even be abandoned as fruitless.

Technology focuses upon the solution of more specific, practical problems by drawing, in large part, on existing knowledge and theory. For that reason its future course can be assessed with greater confidence. If adequate support and a sufficient scientific base exists, time periods on the order of a decade are required to initiate and carry a development to completion. Thus most technological innovations that are likely to be available in five years are already, today, in an advanced stage of development. Major new insights derived from basic and even applied research are unlikely to accelerate such developments, though they may suggest more effective ways to proceed in the future. Twenty-year predictions for developments requiring a decade to complete are more difficult to make, since new research results can make a significant difference if they are incorporated at the initial planning stage. Such predictions are somewhat more reliable for developments that approach or exceed a twenty-year time scale, though even in these cases new research results can alter both the course and prospects of those developments.

How, then, can statements that are useful to policymakers and that have significance over a five-year time scale be made about opportunities and problems for science and technology? One answer assumes that, barring a severe national emergency (such as war or a major depression), most of the important social and economic effects of science and technology that will be apparent in five years will be the result of discoveries already made and developments already well underway. Decisions about priorities for science and technology made during the next five years, however, can and will have measurable effects in the period *beyond* the next five years. Thus, a five-year outlook can describe laboratory and technological developments now underway whose effects are likely to be apparent in five years. It can point to areas of scientific research that are likely to yield sufficient results in five years to permit us to define the prospects for particular lines of technological innovation. Finally, a five-year outlook can speculate about possibilities that could exist in the more distant future, given the persistence of present trends, suggest the types of policy decisions and preparations that would have to be made during the next five years to realize or change those possibilities, and explore the broad social consequences that might follow if those long range possibilities were realized.

All three types of statements appear in this *Five-Year Outlook*.

PLAN AND PREPARATION OF THE FIVE-YEAR OUTLOOK

When the National Science Foundation initiated the design of this, the first *Five-Year Outlook* prepared in response to the Science and Technology Policy, Organization and Priorities Act of 1976, it was aware that no real models or prototypes existed for the type of report defined by the Act. Consequently, the Director of the National Science Foundation, in consultation with the Office of Science and Technology Policy, decided that this *Five-Year Outlook* should be regarded as an experimental, pilot project that would be useful in its own right, and could also provide guidance for the preparation of subsequent *Five-Year Outlooks*.

It was further decided that the *Five-Year Outlook* would be prepared in two steps, and that decision is reflected in its structure. In the first step, self-contained contributions were invited from several different sources. These contributions sample the views of scientists, engineers, administrators, and policy researchers about problems and opportunities in science and technology and about the probable impact of science and technology on issues of policy interest. In the second step, opportunities, problems and policy questions that appear to warrant special consideration during the next five years were extracted from these sources and synthesized under eight topical headings.

Thus, the source materials which make up Volume II are divided into three sections: (1) a report prepared by the National Academy of Sciences (NAS) which focuses on current and emerging problems and opportunities in selected areas of science and technology; (2) reports prepared by 21 U.S. Government agencies that discuss opportunities and problems in the relationships of science, technology and public policy from the perspectives of the individual agency missions; and (3) papers commissioned from individual specialists which provide their views and assessments concerning the relationships between science and technology, public policy and practice and selected socioeconomic goals. The views expressed by the National Academy of Sciences' report and by the specialists who contributed policy-oriented papers to Volume II are their own and do not necessarily reflect the views of the Director of the National Science Foundation or the United States Government. However these contributions, together with the U.S. Government agency reports, do provide a broad, if necessarily incomplete, range of perspectives on problems and opportunities in the relationships of science, technology and other areas of public concern.

The contents of Volume I were written entirely by the National Science Foundation, which bears sole responsibility for them. The topical syntheses that follow this Introduction are based, in part, on a preliminary analysis of the source materials by Dr. John Pierce, Professor of Electrical Engineering, California Institute of Technology. They highlight the source materials by identifying and describing the most significant opportunities and problems in several broad areas—for example, energy, materials, agriculture, and health—in which science, technology and public policy and practice are interrelated. Although the source materials include reports from services and agencies of the Department of Defense, subjects strictly taken from defense science and technology are not discussed in the summary sections that follow. Such discussions would require access to materials that are unavailable to the general public for reasons of national security.

Volume I also includes a synopsis of the agency reports and commissioned papers, which was prepared by, and is the responsibility of, the National Science Foundation. This synopsis is intended to serve as a guide to these materials. The views expressed in the synopsis of the commissioned papers, like the papers themselves, are not necessarily those of the Director of the National Science Foundation or the United States Government. Acknowledgements and an analytical index to both volumes complete Volume I.

Each of the contributions to the source materials that appear in Volume II was reviewed and in most instances revised before the final manuscript was assembled. In addition, the complete draft manuscript of both volumes was evaluated late in October 1979 by reviewers representing the perspectives of state and local government, academia, industry, professional scientific and engineering societies, law, medicine and the broader public interest. Many of the comments and suggestions made by reviewers have been incorporated into this *Five-Year Outlook*. Others will shape the design of the next *Five-Year Outlook*.

The methods that were used to prepare and evaluate the materials of Volume II varied, depending on their nature and source. The report of the National Academy of Sciences (NAS) was prepared by a steering committee chaired by Dr. Ralph E. Gomory of the International Business Machines Corporation and composed of those who were principally responsible for the preparation of the chapters. NAS established a two-tier review procedure: a review of initial drafts by members of the NAS, the Institute of Medicine, the National Academy of Engineering, and units of the National Research Council; and a final review, before release of the report to the National Science Foundation, by the Governing Board of the National Research Council. The final report was transmitted to the National Science Foundation on March 30, 1979. A commercially published edition is available from W.H. Freeman and Company, San Francisco.

Contributions to the *Five-Year Outlook* were requested from all U.S. Government departments, agencies and bureaus whose estimated obligations for research and development for fiscal year 1978 exceeded $100 million. The Department of Housing and Urban Development, the Department of State, and the Food and Drug Administration were also invited to submit reports. Collectively, these 21 departments, agencies and bureaus are responsible for 97 percent of the total Federal obligations for research and development. In requesting contributions to the *Five-Year Outlook* from the heads of these organizations, the Director of the National Science Foundation emphasized the importance of addressing their respective concerns in the context of the National Science and Technology Policy, Organization and Priorities Act of 1976. Individual reports were evaluated and cleared according to the internal procedures of the respective organizations, and with the cooperation of appropriate examiners of the Office of Management and Budget, before release to the National Science Foundation in late August 1979. The full set of reports was then edited to achieve a consistent format.

Topics and authors for the individual commissioned papers were determined by the National Science Foundation staff following consultations with individuals from a broad range of organizations, including academic institutions, private industry, labor, public interest groups, and from several U.S. Government agencies, including the Office of Science and Technology Policy. Drafts were sent to technical experts for review. Most of the drafts were revised by their authors to incorporate the significant comments of those reviewers. The last of the revised papers was delivered to the National Science Foundation by mid-September 1979, after which the full set was edited to achieve a consistent format.

Shortcomings were expected, and some of those that are now apparent should be mentioned. Given the scope of all science and technology in the United States, as well as the size of the family of disciplines that comprise science and technology, it could not be expected that the report would cover all important fields or all significant national policy concerns related to them. The topical syntheses of Volume I are based on the materials in Volume II and of necessity reflect their selective approach. The selections made by the National Academy of Sciences' report were not intended to reflect relative merits or priorities and many significant areas, such as mathematics, chemistry and many of the social sciences, were deferred for inclusion in future reports. The set of commissioned papers is intended to illustrate several types of interactions among science, technology and current national concerns rather than to represent the entire range of significant policy issues associated with science and technology. They were written by individuals who were asked to provide their expert views rather than the consensus of an entire scholarly field. In some cases more than one paper on a particular issue was commissioned in order to present alternative views or assessments. Discussions of several additional policy issues, including the status of basic research in industry, the comparative performance of U.S. technology, commercialization of science and technology, risk assessment, and science literacy, appear in the first and second *Annual Science and Technology Reports*, which were also prepared in response to Public Law 94-282.

Since contributions to the source materials were prepared by different individuals or organizations, they inevitably reflect the expertise and perspectives of their authors. And because most of these contributions review current and immediate problems and opportunities rather than attempt to provide original insights, much of the information in Volume II can be found in other published sources. Thus, this *Five-Year Outlook's* primary claim to originality must rest upon the assembly, organization and interpretation of the information and insights derived from diverse sources. It presents a collage of problems and opportunities over a broad range of science, technology and policy rather than a set of individual in-depth studies.

A good deal of the material in this *Five-Year Outlook* is concerned with the relationships of science and technology with other sectors of society. Therefore, developments in areas outside of science and technology (international upheavals, the state of the national economy, or particular legislative initiatives) will limit the reliability of conjectures about the future. In many cases trends in these areas may be even more difficult to predict than are trends in science and technology.

Finally, no attempts have been made to provide quantitative predictions of likely developments of policy interest, although available assessments based in part on such prediction (in the summary discussion of energy supplies, for example) are referred to when they are regarded as reliable. Quantitative techniques do exist for making forecasts about econometric and demographic aspects of issues of national concern. But the methodology for carrying out quantitative forecasting of other aspects of these issues is not available.

Despite these limitations, the National Science Foundation believes that this *Five-Year Outlook* provides a useful sample of the range of current problems and opportunities associated with the mutual relationships of science, technology and society. It remains to be seen whether it will also serve the stated objective of setting a useful precedent for the design and production of future *Five-Year Outlooks*. The attainment of that objective will require, at a minimum, that users and potential users make their comments, suggestions and criticisms known to the National Science Foundation.

NOTES

1. Roosevelt, Franklin D., Letter to Vannevar Bush dated November 17, 1944, reproduced in Bush, V., *Science—The Endless Frontier*, issued July 5, 1945, reprinted July 1960. Washington, D.C.: National Science Foundation, pp. 3-4.

2. Bush, op. cit., pp. 177-178. Reliable information on the numbers of PhD's awarded in the social sciences and engineering or about numbers of scientists and engineers employed in R&D activities prior to 1954 is not available.

3. National Science Board, *Science Indicators 1978*. Washington, D.C.: U.S. Government Printing Office (1979), Tables 5-4 and 5-23.

4. Bush, op. cit., pp. 85-89. Since the methods used for determining research expenditures in 1940 are not specified in detail in this reference, care should be taken in making direct quantitative comparisons with post-1960 data.

5. National Science Board, op. cit., Tables 2.3, 2.7 and 2.12. The preliminary 1977 numbers and estimated 1979 numbers that appear in these tables have been replaced by more recent data compiled by the National Science Foundation's Division of Science Resources Studies.

6. Ibid.

7. Ibid.

8. Bush, op. cit., p. 4.

9. Bush, op. cit., p. 11.

10. National Science Board, *Science Indicators 1976*, Washington, DC: U.S. Government Printing Office (1977), pp. 168-182; National Commission for the Protection of Human Subjects, *Special Study: Implications of Advances in Biomedical and Behavioral Research*, U.S. Department of Health, Education, and Welfare, DHEW Publication No. (OS) 78-0015 (1978), pp. 25-35.

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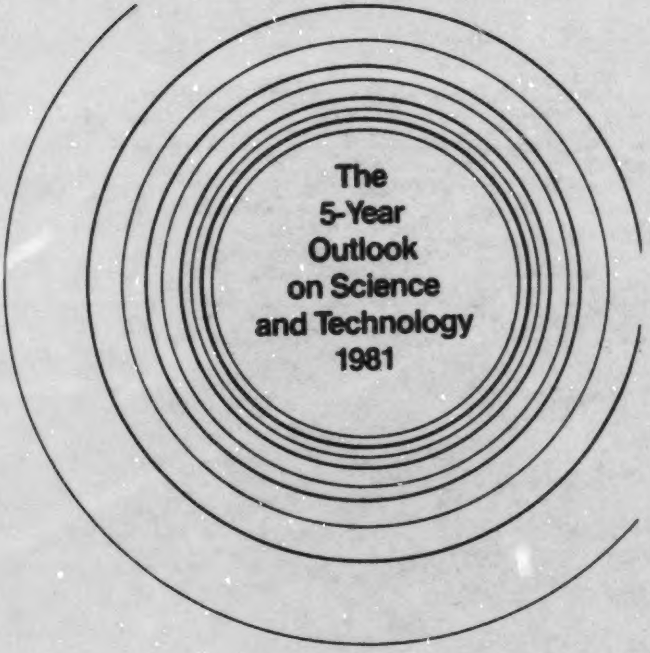
SECOND NSF OUTLOOK REPORT



The 5-Year Outlook on Science and Technology 1981

National Science Foundation

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NATIONAL SCIENCE FOUNDATION
WASHINGTON D.C. 20550

OFFICE OF THE
DIRECTOR

January 26, 1982

To the President and Members of Congress:

I am pleased to transmit the second *Five-Year Outlook* on science and technology as required by the National Science and Technology Policy, Organization and Priorities Act of 1976.

This *Five-Year Outlook*, like its predecessor, is based on the premise that discoveries and inventions pouring forth from the Nation's science and technology enterprise will continue to have a profound influence on all aspects of our lives. The report identifies an array of emergent issues that are likely to be of concern to American society during the next five years. It describes some of the problems, opportunities, and constraints associated with the use of science and technology to help define, illuminate and resolve those issues, and it examines several of the problems that may emerge as a result of scientific and technological activities themselves.

In preparing this report, the Foundation obtained the views of a number of scientific organizations, as well as a range of Federal departments and agencies. These contributions, collected in two accompanying *Source Volumes*, reflect the vigor and diversity of American science and technology, and I commend them to your attention. Several themes persist amid this diversity: the shared responsibility of the public and private sectors for maintaining the strength of the Nation's science and technology enterprise; the vital contributions of science and technology to industrial innovation, productivity and economic growth; the changing international context of American science and technology; the need to base an ever-widening range of policy decisions on better scientific information; and the need to improve the level of scientific and technological literacy of all Americans to enable them to participate more productively in our increasingly technological society. Views of Government and non-Government specialists on each of these topics are drawn together in this report and highlighted in its Executive Summary. We have also synthesized their views about likely near-term problems, opportunities and constraints associated with the applications of science and technology in such specific areas as agriculture, energy and the environment, health, national security, and space.

I believe that this *Five-Year Outlook* provides a useful framework for discussion in the Executive Branch, the Congress, and throughout the Nation about the best ways to focus our superlative national capabilities in science and technology to help increase productivity and economic growth, strengthen our national defenses, make more effective use of our human resources, and improve the quality of our lives and our environment.

Respectfully,

John B. Slaughter
John B. Slaughter
Director

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Preface

The *Five-Year Outlook* on science and technology and its companion, the *Annual Science and Technology Report to the Congress*, are required by Title II of the Science and Technology Policy, Organization, and Priorities Act of 1976 (Public Law 94–282). Both reports are concerned with current and anticipated developments in science and technology and the effects of those developments on society. Both are designed to provide a partial response to the need, expressed by that legislation, for the Congress to be "regularly informed of the condition, health and vitality [of science and technology, and] the relation of science and technology to changing national goals" (Section 102(b)–(6)) and for the executive branch to be able to "identify and assess emerging and future areas in which science and technology can be used effectively in addressing national and international problems" (Section 205(a)–(10)).

Preparation of the two reports is the responsibility of the Director of the National Science Foundation (NSF). Taken in conjunction with the National Science Board's *Science Indicators*, also prepared by NSF, they aim to provide a set of tools useful for policy planning and assessment. More broadly, they are intended as a framework for dialog among the executive and legislative branches of the Federal Government, practitioners and users of science and technology in the public and private sectors, and the general public. *Science Indicators* provides quantitative information, with some analyses, about recent trends in the resources devoted to science and technology and about some quantifiable impacts and outputs of scientific and technological activities. The *Five-Year Outlook* offers a more qualitative and, in some sense, complementary view of present and likely future trends. It identifies and describes current and anticipated developments in science and technology as well as trends external to science and technology that are likely to have impacts on their conduct. The *Five-Year Outlook* also suggests ways in which research can contribute to illuminating and resolving problems of national concern, and it points to constraints on the capacity of science and technology to make such contributions. The *Five-Year Outlook* is not meant to, nor does it, represent the official policies of the U.S. Government. Rather, it serves as an interagency discussion document and a focus for raising problems that might merit policy consideration in the coming years. The *Annual Science and Technology Report*, on the other hand, is a comprehensive statement of the Administration's science and technology policy. It discusses specific issues of concern to the Administration, selected because they are both timely and important, and because the Federal Government has a legitimate and significant role in their solution. The *Annual Report* also reviews Federally supported research and development activities throughout the Government.

The two chapters that compose the body of the second *Five-Year Outlook* on science and technology aim at two different, but related, objectives. Chapter I focuses on the impacts that science and technology are likely to have on problems that transcend or cut across specific substantive fields or areas of application and on the ways in which developments external to science and technology are likely to affect their conduct. Its emphasis is on trends associated with four generic topics that are likely to continue to be important for at least the next 5 years: (1) Maintenance and Development of the Science and Technology Base; (2) Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth; (3) The International Context of U.S. Science and Technology; and (4) Science, Technology, and Policymaking.

Chapter II is concerned with the probable effects of developments in science and technology in specific areas of application. It discusses issues associated with nine functional categories: (1) National Security, (2) Space, (3) Health, (4) Energy, (5) Natural Resources, (6) Environment, (7) Transportation, (8) Agriculture, and (9) Education.

All the broad themes that underlie the discussions in the two chapters are drawn from source materials commissioned by NSF. Other published sources were also used occasionally to provide additional factual information or to amplify the discussions.

The commissioned materials are published in two *Source Volumes*. The first volume consists of 17 chapters prepared by the National Research Council on human resources, natural resources and environment, research frontiers, research systems, and new technologies. The chapters offer the perspectives of individuals active in research in those areas. They do not necessarily reflect policies of the National Science Foundation or the U.S. Government.

The second volume of source documents consists of the views of individuals selected by two organizations—the Committee on Science, Engineering, and Public Policy of the American Association for the Advancement of Science, and the Social Science Research Council. Their contributions deal, respectively, with public policy problems associated with science and technology, and with current developments in social and behavioral science disciplines. Again, the views and opinions expressed do not necessarily reflect the policies of the National Science Foundation or the U.S. Government.

The second of the *Source Volumes* also includes narratives prepared by task groups representing 22 Federal agencies. They deal with anticipated problems, opportunities, and constraints related to science, technology, and public policy from the perspectives of the missions of those agencies. Finally, the second *Source Volume* includes a selected, annotated bibliography of published sources and an index to both *Source Volumes*.

Notes concerning the preparation of the *Five-Year Outlook* and the source materials appear in Appendix B.

Key to Abbreviations

Abbreviations appearing in parentheses throughout Chapters I and II refer to more complete discussions in the *Source Volumes*, to sources contributed to the first *Five-Year Outlook*, and to recent *Science Indicators* and *Annual Science and Technology Reports*. Citations to the published literature appear as footnotes.

Table 1—Key to Abbreviations Used in the Text to Cite Source Materials

Abbreviation	Explanation
Nongovernment Sources	
NRC-1,2,3	Contribution of the National Research Council (in *Source Volume 1*) by chapter number. Note: NRC-Obs. refers to the discussion titled "Observations," by F. Seitz and P. Handler
AAAS-1,2,3	Contribution of the American Association for the Advancement of Science (in *Source Volume 2*) by chapter number. Note: AAAS-Obs. refers to the discussion titled "Observations: Racing the Time Constants," by W. D. Carey
SSRC-1,2,3	Contribution of the Social Science Research Council (in *Source Volume 2*) by chapter number
Federal Agency Task Group Narratives (In *Source Volume 2*)	
NS	National Security
SPACE	Space
HEALTH	Health
ENERGY	Energy
GST	General Science and Technology
NR	Natural Resources
ENVIRON	Environment
TRANS	Transportation
AGR	Agriculture
EDUC	Education
IA	International Affairs
Other Selected NSF Reports	
Outlook 1	First *Five-Year Outlook*, 1980
ASTR-I,II,III	*Annual Science and Technology Reports*: I = 1978, II = 1979, III = 1980
SI-78; SI-80	*Science Indicators* series: 78 = 1978, 80 = 1980

Executive Summary

America's capabilities in science and technology have provided the basis for its immeasurable contributions to human knowledge about the natural and the manmade universe. The deliberate and systematic application of that knowledge has, in turn, contributed to improvements in the quality of life and the environment, increased industrial and agricultural productivity, economic growth, and national security. Science and technology have provided detailed information and analytical tools to assist in weighing an array of policy options and in assessing the impact of policy choices. And science and technology have become important adjuncts to American foreign policy.

This *Five-Year Outlook* is based on the premise that the unmistakable influence of science and technology on contemporary trends and outcomes is unlikely to abate. It identifies an array of emerging national issues with high science and technology relevance that are likely to confront the United States during the next 5 years. It describes some of the problems, opportunities, and constraints associated with the use of science and technology to resolve those issues, and it examines problems that may emerge as a result of scientific and technological activities themselves.

The issues described in this report have been identified in contributions from the National Research Council, the American Association for the Advancement of Science, the Social Science Research Council, and a wide range of Federal agencies whose missions involve science and technology. Many of the issues are generic in the sense that they transcend or cut across specific substantive fields or acknowledged areas of application. Those issues are identified and described in Chapter I—and summarized below—under four headings: (1) Maintenance and Development of the Science and Technology Base; (2) Contributions of Science and Technology to Industrial Innovation, Productivity, and Economic Growth; (3) The International Context of U.S. Science and Technology; and (4) Science, Technology, and Policymaking. Other current and emerging issues center on problems, opportunities, and constraints that are closely related to particular substantive fields. Those problems, opportunities, and constraints are identified and described in Chapter II—and summarized below—under nine topical headings, each corresponding to one of nine functional categories: (1) National Security, (2) Space, (3) Health, (4) Energy, (5) Natural Resources, (6) Environment, (7) Transportation, (8) Agriculture, and (9) Education.

Generic Policy Issues*

MAINTENANCE AND DEVELOPMENT OF THE SCIENCE AND TECHNOLOGY BASE

The ability of American science and technology to sustain their record of achievement will depend on maintaining and developing the superlative infrastructure established with public and private support since World War II. Retrospective indicators demonstrate convincingly that the United States has maintained its preeminence in scientific research during the past 5 years. But signs of stress, including resource constraints, demographic trends affecting higher education, escalating instrumentation costs, and pressures for short-term returns on research investments, may well become more pronounced during the next 5 years. With respect to technology, the United States is no longer the undisputed world leader, as it was a decade ago, in such basic areas as automotive design, consumer electronics, scientific instrumentation, steelmaking, ship construction, and rail transportation, in part because Japan and Western Europe have reestablished the intellectual and productive capacities that were destroyed by World War II. It is losing its lead in several key defense-related technologies. As yet there is no evidence of any diminution in the inventive capacity of American scientists and engineers; rather, many perceive a failure in following up and implementing their innovations. Yet the above noted stresses, if they do not abate, could seriously erode the science and technology base and therefore its innovative capacity (pp. 2–3).

FINANCIAL RESOURCES

Total (civilian and military) national investments in research and development (R&D) in the United States are greater than in France, West Germany, and Japan combined. The ratio of total annual national investments in R&D to Gross National Product (GNP) declined in the United States since 1967, but it is still higher than in all other countries, with the possible exception of the Soviet Union. The U.S. civilian R&D per GNP ratio has plateaued at about the same level as in the United Kingdom and France, but considerably below that of West Germany and Japan. Moreover, R&D investments in those two countries are more sharply concentrated in areas related to economic growth than is true in the United States (pp. 3–4).

During 1981, total national expenditures for all R&D activities in the United States were estimated to be $69.1 billion, with the Federal and industrial shares estimated at 47 percent and 49 percent, respectively. Of the Federal expenditures, approximately one half were allocated to national security. National expenditures for basic research during 1981 were estimated to be $8.8 billion, with the respective Federal and industrial shares estimated at 68 and 16 percent (p. 3).

Financial resources in the private sector for conducting R&D are likely to remain constrained during the next 5 years, although improved economic conditions are expected to increase prospects for private sector investments. Thus, there are likely to be continuing incentives for structural changes that might facilitate research, including greater use of centralized facilities and cooperative projects between university and industrial laboratories. Cooperation among government, universities, and industry in several defense-related areas of basic science and engineering will likely increase (pp. 10–12).

HUMAN RESOURCES

If present undergraduate enrollment trends persist, there should continue to be enough new graduates in most broad fields of science and technology to satisfy anticipated demands through the decade. However, spot shortages do exist in certain subspecialties, and others may develop. The greatest problems at present appear related to engineers and computer scientists. University faculties, the armed services, and, in some critical fields, private industry are likely to continue to experience difficulties in recruiting and retaining qualified engineers and computer scientists, particularly persons with advanced degrees (pp. 7–8).

UNIVERSITY RESEARCH

At present, universities and colleges and organizations associated with or administered by universities conduct about 10 percent of all the R&D in the United States and about 50 percent of all the basic research. Universities are likely to continue to experience problems related to the costs of carrying out their activities and the decreasing college age population from which undergraduate and graduate students are drawn. Instrumentation obsolescence in such equipment-intensive fields as physics, chemistry, computer science, and the various fields of engineering is likely to continue as a serious problem. Openings for new Ph.D's in many university science departments are likely to remain scarce into the next decade (pp. 8–10).

The numbers of Ph.D's awarded in engineering and computer science have been decreasing since the early 1970s. In contrast, and unlike the situation in most scien-

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*Page numbers in parentheses refer to detailed discussions in the body of the *Five-Year Outlook*.

tific disciplines, undergraduate enrollments in engineering and computer science have been increasing, and applications for admission to programs in these fields are projected to increase. However, unless current faculty recruitment problems are resolved, university engineering and computer science departments may not be able to maintain enrollments at a level sufficient to continue to meet anticipated demand at the bachelor's degree level. In addition, the lack of sufficient numbers of qualified faculty members, coupled with the growing obsolescence of instruments and facilities, could have a negative effect on basic engineering research in the country (pp. 8–10). A similar problem appears to be developing in medical science as a diminishing proportion of young physicians opt for careers in research and teaching. That trend has already led to vacancies on several medical school faculties (p. 49).

INDUSTRIAL RESEARCH

Approximately 70 percent of all R&D in the United States is conducted by private industry. During the next 5 years a good deal of industrial research is expected to focus on improving energy efficiency in processing and on increasing productivity through automation, with the relative importance of those concerns differing among industries and among firms within industries (pp. 10–12).

Since the mid-1960s there has been a shift away from investments in long-range research in several key U.S. industries, a factor that may have contributed to the erosion of U.S. leadership in certain technological areas. Industrial investments in long-range exploratory research during the next 5 years will almost certainly depend heavily on the severity of foreign competition, the general economic situation, and the likelihood that the legal and regulatory climate will not unduly impede the commercialization of results of R&D activities. Changes in U.S. tax laws during 1981 were designed in part to stimulate increased industrial investments in long-range R&D. Industrial laboratories are also likely to seek to strengthen their links to other components of the U.S. research system, particularly universities (pp. 10–12).

CONTRIBUTIONS OF SCIENCE AND TECHNOLOGY TO INDUSTRIAL INNOVATION, PRODUCTIVITY, AND ECONOMIC GROWTH

During the 1970s, the growth rate of American industrial productivity lagged behind that of other industrialized countries, including France, West Germany, and Japan. In addition, the rate of industrial innovation in the United States also appears to have lagged relative to those countries. Total industrial R&D investments in those countries are also increasing faster than in the United States.

CONTRIBUTIONS OF SCIENCE AND TECHNOLOGY

A number of factors influence industrial innovation, productivity, and economic growth. Research and development activities are among the more important, since they underlie the innovation process and provide many of the tools needed for increasing productivity. Productivity growth also appears to be related to long-term investments in basic research; American industries with high ratios of R&D investments to sales have consistently experienced substantially higher productivity growth rates than other industries. There is no evidence of any diminution in the innovative capacity of U.S. scientists and engineers. Rather, low rates of productivity growth in some industries may derive from a failure to make sufficient use of R&D results (pp. 12–13).

Productivity can also be improved by incorporating existing innovations into industrial processes and through the successful application of organizational behavior data, as Japan has demonstrated in the automotive and consumer electronics industries. Additionally, technological innovations based on the results of R&D activities can lead to improvements in the quality as opposed to the quantity of goods and services, although such qualitative improvements are not easily translated into measures of productivity changes (pp. 12–16).

INDUSTRIAL R&D INVESTMENTS

While total real dollar outlays for R&D by private industry have increased substantially since 1975, there has also been a marked shift away from long-term exploratory research toward short-term problem solving in several key industries. Factors beyond the control of industry can discourage long-term R&D investments. They include generally high inflation and interest rates, escalating energy costs, Federal tax and patent policies, and Federal regulations that encourage short-term defensive research and lead to uncertainties about the future marketability of R&D results (pp. 13–15).

The shift away from long-term investments and the failure to capitalize on existing innovations in some industries may also be related to internal management practices, to recruitment procedures that select managers on the basis of business skills rather than technical comprehension, and to a reward system that emphasizes realizing short-term profits rather than investing in long-range innovative potential (p. 15).

THE FEDERAL ROLE

During the next 5 years, the Federal Government is expected to focus on indirect means of encouraging private industry to increase its long-term research investments and on improving the climate for commercializing the results of its R&D activities. In addition to improving the overall economic climate, the 1981 Economic Tax Recovery Act included R&D tax credits, accelerated depreciation schedules, and other incentives to stimulate additional corporate R&D investments. More favorable patent and antitrust policies, as well as removal of disincentives in the form of excessive Federal regulations are also likely to stimulate such investments. Many believe that the appropriate Federal role is to support only long-range, high-risk research with a potentially high payoff. Thus, the Reagan Administration is not expected to support R&D programs of an economic subsidy nature except in areas such as defense and space where Government is the sole or primary consumer (pp. 16, 17).

INDUSTRY-UNIVERSITY COOPERATION

Increased university-industry cooperation appears to be an important element in strengthening this country's R&D enterprise. Such cooperation can take a number of forms, including contracted research, jointly owned and operated research facilities, and university-based industrial institutes. Cooperation offers industry additional access to long-range exploratory research programs as a source of ideas, knowledge, and basic technologies for future innovation. It provides universities with additional sources of research support and gives university faculties and students access to industrial research facilities and a more realistic understanding of both the needs of industry and available industrial research opportunities. The trend toward greater research cooperation between industry and universities appears to be largely independent of direct Federal intervention. Anticipated increases in university-industry cooperative research during the next 5 years should provide data on the effectiveness of various cooperative modes and on the need for catalytic Federal support (p. 17).

THE INTERNATIONAL CONTEXT OF U.S. SCIENCE AND TECHNOLOGY

During the next 5 years, trends and events abroad, particularly in Western Europe, Japan, and the U.S.S.R., will affect U.S. relations with those countries, the conduct of American science and technology, and the relationships of science and technology to U.S. domestic concerns. The Federal Government is likely to continue to support international collaborative efforts in science and technology when such collaborations are clearly in the national interest. Issues associated with international resource management and the global environment will persist on the U.S. domestic agenda, as will the perennial problem of how best to use science and technology to help resolve problems related to poverty throughout the world (p. 18).

INTERNATIONAL COOPERATION

The industrialized democracies, particularly the Western European nations, share many concerns about likely effects of financial and human resource constraints on the conduct of science and technology. Thus, incentives for cooperative international science and technology programs, particularly large, expensive programs of mutual interest and benefit in such areas as space and high-energy physics that are unlikely to provide any single country with a short-term competitive edge, may well increase. Such cooperation is expected to continue under the auspices of official bilateral and multilateral government agreements, through multinational corporations, and through private arrangements between individuals, research organizations, and business firms (pp. 18–20).

INTERNATIONAL COMPETITION

Domestic policies affecting R&D can have serious impacts on U.S. competitiveness abroad. For example, since regulatory policies among the industrialized democracies vary, such American industries as the pharmaceutical industry may be at a disadvantage compared to their foreign competitors. The effects of regulations on international technology competition need continuing examination, on a case-by-case basis, during the next 5 years. Possible effects on U.S. industry of additional tariff barriers or additional high-technology export limitations also need to be examined closely, particularly in view of the vital contributions that R&D-intensive industries are making to the U.S. balance of payments (pp. 18–20).

SOVIET CAPABILITIES IN SCIENCE AND TECHNOLOGY

The U.S.S.R. appears to invest a larger fraction of its Gross National Product in R&D and has a higher proportion of its labor force engaged in R&D activities than any other nation. Soviet scientists have made impressive contributions in several disciplines, and the country has made significant strides in applying R&D in nuclear energy development, civil and military space activities, and national defense. However, the Soviet Union has thus far failed to use its massive R&D investments for fostering innovations in manufacturing industries and for economic growth. Improvements in the productivity of the Soviet labor force have fallen sharply in recent years. The Soviet leadership appears to recognize that with labor, energy, and capital constraints becoming more severe, the country's productivity will have to improve rapidly to meet even its modest economic growth targets; however, Soviet leaders appear unwilling to take the necessary steps to improve productivity. The centrally planned nature of the Soviet economy, the rigid institutional barriers that exist between the R&D and the industrial sectors, and the absence of any strong economic driving force may be difficult obstacles to overcome in stimulating innovation and economic growth (pp. 20–21).

The appropriate degree and form of science and technology cooperation with the U.S.S.R. depends on many factors. The political climate between the United States and the Soviet Union plays a large role in determining the volume of these exchanges, as does the willingness of the Soviets to provide access to their best scientists and facilities. Many U.S. scientists have decided to boycott exchanges with the Soviets over the treatment of their fellow scientists, such as Sakharov, Orlov, and Brailovsky, in the Soviet Union. Past governmental bilateral scientific exchanges have provided the United States with a window into Soviet science, even though the Soviet scientists probably gained more in a scientific sense than their American counterparts. The efficacy of controls on the exports of nonmilitary technologies is also a difficult issue, in part because of the difficulty of prohibiting or limiting access to a good deal of widely available scientific and technical information (p. 21).

RESOURCE MANAGEMENT AND ENVIRONMENTAL ISSUES

Ensuring the availability of oil and other critical raw materials, including metals and certain specialized woods, will continue to be a central problem for all industrialized nations. With the industrialization of several middle-tier countries, it is likely to become a more difficult problem internationally. Thus, there are likely to be increasing incentives for cooperative efforts to apply science and technology to improve mineral resources exploration, recovery, processing, and recycling techniques as well as the development of substitute materials. Cooperative efforts to improve management of the world's tropical forests and prevent or reverse desertification of arid lands can provide both short- and long-term benefits for the United States. Assessments of the causes and probable long-term effects of pollution in the oceans and of increasing fluorocarbon and carbon dioxide concentrations in the atmosphere will also require continuing attention (pp. 21–22).

PROBLEMS OF ECONOMIC DEVELOPMENT

Three related problems will continue to constrain economic development in many less developed countries: population growth, increasing food supply pressures, and escalating world demand for petroleum. At least until the middle of the next century, those problems are likely to be regional rather than global because they will fall more heavily on the poorer countries rather than threatening the carrying capacity of the entire world. Most analysts agree that the United States cannot continue indefinitely to bear the major burden of food production for the world, and that, therefore, agricultural productivity in the less developed countries needs to be increased (pp. 23–24).

One of the most effective ways in which individuals and institutions in industrialized countries can help the less developed countries realize their long-range development objectives is to continue to assist them in building their own indigenous science and technology capabilities. President Reagan recognized the effectiveness of this mode of cooperation in his pledge to devote greater amounts of scientific and technical know-how to third world problems. Such indigenous capabilities are essential for devising new technologies or adapting existing technologies to local needs, for weighing alternatives among available foreign technologies, and for assessing probable impacts of different options for technological development (pp. 24–25).

SCIENCE, TECHNOLOGY, AND POLICYMAKING

The sheer amount of information, including scientific information, available to assist in policymaking processes will continue to grow during the next 5 years, as will the capabilities for handling, manipulating, communicating, and retrieving it. For those reasons, the problems of how to gain ready access to usable data that already exist are likely to become more serious concerns in both the public and the private sectors (pp. 25–26).

METHODOLOGICAL IMPROVEMENTS IN GATHERING AND INTERPRETING DATA

The power of scientific information to help define and illuminate policy problems and assess the impacts of policy decisions has been enhanced considerably through the use of conceptual and analytical tools developed by various scientific disciplines. Methodological improvements are expected to strengthen the reliability of survey results concerned with the characteristics, actions, and opinions of large groups, as well as the validity of demographic projections and certain types of economic projections. Improved methodologies should also permit better interpretation of the data bases that have been gathered systematically for the past 20 years about the current and changing status of various institutions, including industrial firms, educational institutions, scientific organizations, and government at all levels (pp. 26–27).

SCIENTIFIC INFORMATION AND THE REGULATORY PROCESS

During the next 5 years both the public and private sectors will probably make considerable use of scientific information in assessing risks to health, safety, and the environment. A February 17, 1981, Executive Order of the President requires that Federal regulations of hazardous technologies be justified by weighing the costs and benefits of the technologies themselves and of the proposed regulations. Estimating levels of possible damage from a particular pollutant or contaminant can be greatly facilitated by a detailed understanding of fundamental physical, chemical, biological, and physiological processes, a fact arguing in favor of wide-ranging, sustained basic research (pp. 27–28).

Additionally, a good deal of attention is likely to be directed to the uses and limitations of formal risk assessment and cost-benefit analyses and other analytical tools for assessing risks and for weighing risks, costs, and benefits. A particular need is to expand these methodologies to permit comparison of the costs, risks, and benefits associated with entire alternative classes of products or processes—for example, comparison of large-scale coal and nuclear fission systems (pp. 28–29).

THIRD NSF OUTLOOK REPORT

The Five-Year Outlook on Science and Technology 1982

National Science Foundation

This report was prepared for the National Science Foundation by the Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The views and opinions expressed herein do not necessarily reflect the policies of the National Science Foundation.

NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550

OFFICE OF THE
DIRECTOR

September 15, 1983

To the Members of Congress:

I am pleased to transmit to you this *Five-Year Outlook* on science and technology, prepared for the National Science Foundation by the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report about trends and opportunities in eight selected areas of fundamental science and engineering is an eloquent testament both to the vitality and richness of contemporary fundamental scientific research, and also to the significance of fundamental research to the attainment of immediate and long-term national goals. Additionally, the report attempts to draw several overarching policy implications from its assessment of trends and developments in these eight areas. While its discussion of those policy implications does not necessarily reflect the views of the National Science Foundation or the United States Government, it does represent the considered judgment of a distinguished group of scientists and engineers. As such, it provides an important basis for informed public discussion of issues related to the continued health of the Nation's science and engineering enterprise.

The most important policy implication that I derive from reading this report is the imperative need to strengthen the links among the varied institutions that comprise the U.S. scientific enterprise so that the enterprise can, collectively, better realize its considerable potential to contribute to national goals. This need has been recognized and assigned a high priority by the Reagan Administration. Indeed, one of the key elements of the Administration's science policy is to improve the links between laboratory and marketplace, between academia and industry, and between the research and educational functions of academia.

The last of these links is the most important from the perspective of this *Five-Year Outlook*, which attempts to assess trends and probable future developments in science and engineering. The strong links that have been forged between research and graduate education in our universities have been largely responsible for the continued intellectual leadership that U.S. science has enjoyed in so many disciplines for so many years. As this *Five-Year Outlook* indicates, the intellectual state of science and engineering in this country continues to be sound. I am concerned, however, about whether we are getting enough first-rate people into the sciences to sustain our record of excellence into the future.

This Administration recognizes that the support of excellent people both now and in the future is central to the continuing vitality of fundamental research. It is, for example, placing increased emphasis on the support of graduate and even undergraduate assistants on federally supported research projects, as a step toward strengthening the links between research and education. It has taken important initiatives to link mathematics and science education at the precollege level with education and research in our universities. But the Federal Government cannot by itself assure the future vitality of U.S. science and technology. Rather, I am convinced that those who enjoy the excitement and privilege of fundamental research need to recognize our responsibility for the future vitality of the enterprise, and in particular to assume an increased measure of responsibility for education at all levels.

This *Five-Year Outlook* testifies to the excellence of fundamental research in this country. It also represents a challenge to the Congress, to the Executive Branch, and to the scientific community to take steps to assure that that excellence will be sustained. On both grounds, I commend it to your attention.

Respectfully,

Edward A. Knapp
Edward A. Knapp
Director

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Introduction: Science, Technology, and the National Agenda

In stating the purposes of the *Five-Year Outlook*, the United States Congress asked that it identify national problems to which science and technology pertain and that it outline specific opportunities and constraints in their use. The request was—and continues to be—a daunting one, owing partly to the rapidity of scientific and technological progress and to the evolution of congressional priorities. The obvious need to select certain fields of science and engineering for this analysis—and even to select specific topics within each field—simply magnifies the difficulties.

Yet, we believe that the contents of this *Outlook*, reporting on current and future work in eight growth points of American science and technology, respond directly to the congressional aim to draw more fully the relation of science and technology to the very large and kaleidoscopic agenda with which the nation must deal.

The intent of this chapter is to discuss the relation to congressional concern of work in the eight fields selected. A second intention is to outline overarching themes that become apparent when the eight fields are considered as a whole.

Perhaps the most important theme is the remarkable fertility of American science and technology. New knowledge has provided new ways for understanding diseases. Such fundamental research areas as surface physics and turbulence theory have yielded new technologies and new controls for ancient problems. Assuming real growth in research support, the United States can expect to remain at the forefront of virtually all scientific frontiers in the 1980's and beyond.

IMPLICATIONS—FROM GENETICS TO ROBOTICS

Each chapter of the *Outlook* harbors implications affecting the national agenda. These are indicated briefly below, albeit with the suggestion that either the summaries accompanying each chapter or, more profitably, the full chapters themselves also be read.

The Genetic Program of Complex Organisms (Chapter 1)

Until the 1970's, direct study of the genes of organisms more complicated than bacteria and viruses was constrained by lack of experimental methods. With the advent of recombi-

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This third report on the five-year outlook for selected fields of science and technology was prepared under the chairmanship of Floyd E. Bloom and the aegis of the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The Committee selected the topics, arranged for peer review of each chapter, and contributed to the analysis of the wider implications flowing out of these fields. The Committee also reviewed the entire report and is solely responsible for its contents.

nant DNA and other methods, it became possible to study directly the genes of plants and animals, including those of man. It was then feasible to isolate genes responsible for particular functions, to examine their structure, and to decipher the controls on their operation.

We are in part what our genes make us, and therefore these genetic discoveries of the last 10 years will have global effects—in new insights into how an organism develops from a single fertilized egg, how it grows, and how it ages. We are also gaining new insights into some fundamental aspects of cancer; for example, rearrangements in DNA structure may be common to diverse causes of tumors, including chemical carcinogens and viruses. This work supports a shift in emphasis from the cure to the prevention of cancer. Further, we are now moving to a new level in understanding many inheritable diseases, in mitigating their effects, and in finding new methods of treating some of these once hopeless conditions.

Commercially, the new understanding of gene structure—and the research and technology that made it possible—has led already to new manufacturing techniques for creating otherwise difficult-to-make, often unavailable, and usually expensive molecules. These include insulin for treating human diabetes without the risk of immunological side effects, growth hormones for the prevention of growth abnormalities, and interferon for the possible treatment of certain cancers.

In all, the past decade in molecular biology has been marked by accomplishment, by the creation and maturation of new techniques, and by a sharper definition of questions to be probed. The next five years will provide answers and generate more questions. Also, the new knowledge will yield imaginative solutions to longstanding problems. New and better drugs and vaccines will be manufactured; new and improved plants may be developed, and the yields of existing plants raised; and the diagnoses of diseases will be improved and new treatments of some of these diseases emplaced.

The Molecular and Genetic Technology of Plants (Chapter 2)

Some plants, such as carrots, will grow readily from single cells; others, such as soybeans, will not. No one knows why, reflecting an ignorance at the fundamental level of the regulation and structure of plant genes and of the factors governing the growth of plants. Gaining such knowledge has the potential to quicken the rate of breeding new plants, to raise yields, and to extend agriculture to marginal lands.

Understanding of the genetics of plants now lags that of animal genetics, so the potential remains uncertain but still enormous. Thus, whether improved understanding of plant genetics will yield new plants useful as crops remains speculation. However, the rapid pace of work in the field, marked by increasing university-industry cooperation, will surely aid in breeding more useful agricultural plants. Improved disease resistance, salt and drought tolerance, more efficient photosynthesis—are all targets of a heightened knowledge of plant genetics and the ability to manipulate it.

We may learn how to prompt seeds to accumulate more protein of a higher quality, to increase the efficiency of nitrate use, and to control plant growth and development. As our knowledge of plant genes enlarges so will our capacity for finding faster and less expensive ways to breed crops suited to changing demands and conditions.

Cell Receptors for Hormones and Neurotransmitters (Chapter 3)

The cells of an animal or a plant must function in an integrated manner in order for the organism to survive and reproduce. In turn, integration depends upon the ability of the cells to recognize and respond to such chemical signals as hormones and neurotransmitters. Recognition and response rely on special molecules or structures in cells, called receptors. As in the case molecular genetics, the last decade has been marked by a rapidly growing understanding of what receptors do and how they work.

In brief, receptors enable cells to react to chemical instructions from other cells. If the receptors do not work as they should or are missing, the cell malfunctions; if receptors are occupied by certain drugs or by autoantibodies to them, natural signals may be ignored. The growing knowledge of receptors, particularly since the mid-1970's, is unfolding a succession of applications and insights for a host of possible "receptor diseases" whose causes were previously unsuspected.

Further, receptor research has led to rapid and highly specific methods of following the responses to drugs of healthy and diseased cells. The mechanisms by which cells are able to regulate their responsiveness have been demonstrated. Better guides in treating human breast cancers, which may illuminate approaches to other hormonally responsive cancers, have been developed. A more detailed knowledge of how insulin works has refined our knowledge of various forms of diabetes.

In the next several years, the exact mechanisms of receptors for specific chemical messengers will become better understood. With that, our knowledge at a molecular level of how a given hormone or neurotransmitter actually exerts its effects will be enhanced.

Such knowledge inevitably will be applied to the design of drugs; that is, to finding agents that modulate, enhance, or block the actions of selected chemical messengers at their receptors. We may expect, therefore, a new generation of drugs which are much more specific in their actions and whose pharmacology will be understood at a molecular level. Similarly, approaches to diagnosis, interpreting disease symptoms, and designing treatment strategies will be altered by our heightened awareness of how cells "talk" to each other.

Psychobiology (Chapter 4)

The nerve cells of the brain communicate using chemical and electrical signals to process information through the complex pathways by which we act and think. The search for ways to understand the physical basis of behavior and mind is continuous, difficult, and incrementally successful. A spectrum of implications is emerging from research on the brain. These include improved understanding of psychiatric and neurological diseases, the physical basis of learning, and the effects of aging. Through the use of animals in research, we now have better knowledge of the behavioral abnormalities underlying certain aspects of depression and anxiety.

There has been substantial progress in understanding some forms of deafness, suggesting what might be done about them. Advances in sensory physiology have led to electronic devices that, in a limited way, can substitute for injured eyes and ears, as well as alleviate some forms of chronic pain. Prenatal and perinatal studies are clarifying the causes of some forms of brain damage, while postnatal studies of brain development will aid in improving the education of children and will help them to reach their full capacities.

Surface Science and its Applications
(Chapter 5)

Surface science is concerned with the first few atomic layers at the surfaces of solids and examines the effects of those layers on the rest of the solid and on other materials. All solids, natural or synthetic, have surfaces, and the character of those surfaces—their structure, their electronic nature, and the atoms that they are composed of—can influence the physical and chemical behavior of the entire solid and the interaction of the solid with other atoms and molecules and with external radiation.

With the very rapid miniaturization of electronic devices, the proportion of atoms on the surfaces of integrated circuits—and hence their importance—has increased. Atoms adhering to surfaces can form "surface molecules" having, in some cases, structures not found in the gas phase. Thus, the study of chemistry at surfaces provides new insights into the interactions of molecules—events that, despite their scientific and economic importance, are still not well understood. The chemical and petroleum-refining industries rely on catalysts that speed particular reactions; an improved understanding through surface studies of how catalysts work will translate into more economic chemical processes and also into fewer side products and, hence, fewer environmental problems.

Surface studies may lead to improved corrosion-resistant materials and corrosion-preventing coatings. Surface analytical techniques are improving our knowledge of embrittlement and structural failures. The field ramifies into unlikely areas—for example, into land management, since much of soil chemistry is really colloid chemistry, which in turn is a branch of surface science dealing with small particles at a solid-liquid surface.

Turbulence in Fluids
(Chapter 6)

Moving fluids tend toward turbulence, whether they are air, blood, ocean water, the aerosols of clouds, the oil flowing in pipelines, the lithosphere of drifting continents, or galaxies. Turbulence is disordered fluid flow, and understanding what initiates and maintains it is essential to better prediction and control of turbulent events.

As a practical matter, analysis of turbulence is limited to statistical approximations of what happens in turbulent flow, as distinct from what actually happens. There are now negligibly few ways of predicting turbulence quantitatively. The result is an inability to generalize—to use with confidence—the studies of turbulence associated with a particular turbine design in designing a different type of turbine. Work under way is providing a new way of thinking about turbulence that promises deeper understanding of universally applicable features of turbulent events.

Studies of turbulence may lead to improved design of axial compressors and pumps, military and civilian aircraft, chemical reactors and mixers, and more accurate prediction of ocean currents and weather patterns. Finally, new insights into the origins of disorder in natural systems may contribute not only to understanding fluid turbulence but also to model building in economics and ecology.

Lasers
(Chapter 7)

Lasers are devices in which atoms, molecules, or ions are made to radiate at frequencies corresponding to separations between discrete energy levels. The product is light of essentially a single wavelength and phase—coherent light. Such light is monochromatic, or of one color; highly directional, emerging as a narrow and focused beam; and intense. The wavelength range of laser light has widened considerably in the 25 years since the laser was invented, and many novel applications have emerged. In the next several years, both the uses of lasers and their capacities will expand. Lasers are remarkable, not only for what they have done, but for what they now seem on the verge of doing in a range of important applications, extending from lightwave communications to new medical surgeries and from diagnostics to separating uranium isotopes.

Laser science and technology are now driven by a reverberating dance between device physics and need: an evident application spurring the development of a suitable laser, and a new laser prompting new uses. Examples include flow cytometry, that is, the separation of cells according to their size, shape, and reflective properties, and their further sorting according to, for example, their shape and DNA content—all within minutes. Another illustration is the mode-locked laser which enables scientists to observe events occurring in trillionths of seconds, such as the chemical changes in a chlorophyll molecule triggered by light quanta, leading in turn to an improved understanding of the initial stages of photosynthesis.

The Next Generation of Robots (Chapter 8)

Robots are computer-controlled devices that reproduce human senses, manipulations, and motions well enough to do useful work. They are now being installed in manufacturing plants and, in the next several years, major expansion of their uses and capacities will occur.

Today's robots are usually sedentary, stand-alone arms, with limited precision, little sensory capability, and little if any capacity for dealing with the unexpected; thus, they can work effectively only in highly structured industrial settings.

However, these limitations are being eroded by the application of technical expertise gathered in the past 10 years. Thus, new computer languages will enable quicker, more precise communication between people and robots. New sensors will enable robots to see, to feel, to walk, and to recognize commands. Systems integrating these newly endowed traits are being developed, leading in time to a new generation of robots that can deal with disorder—that can, for example, pick a specific piece out of a bin of jumbled parts. Eventually, robots will grow in numbers and in capacities, and will become a major factor in industrial activity and change.

WIDER IMPLICATIONS

The broad themes derived from these chapters can now be discussed more extensively. They include:

- changing perspectives on health care;
- the faster pace of technological innovation;
- the importance to scientific and engineering progress of the effective use of new communications technologies;
- the emergence of research-based technologies;
- the need to examine federal policies in regard to research and development considered as a whole; and
- the quickening dissolution of the traditional boundaries between the sciences and between science and technology.

Health Care

The nation will face the escalating costs of treating chronic diseases that increasingly incapacitate and kill Americans—heart diseases, cancers, arthritis and related disorders, metabolic diseases, and a wide and complex array of psychiatric and neurological diseases.

These diseases—successors to such acute illnesses as pneumonia, tuberculosis, infantile diarrhea, syphilis, and typhoid fever as leading killers—have causes that remain unknown and develop in patterns not sharp enough to enable invariably successful intervention. Much of the care applied to them is supportive clinical management—costly "halfway technologies."

Yet, as several chapters of this report suggest, we now have new windows into many of these disorders. The unraveling of how messages are transmitted from outside to inside the cell—and what happens when that communication system is disrupted—is in turn clarifying the nature of an increasing number of diseases—hormonal illnesses, such as diabetes, and neurological diseases, such as myasthenia gravis.

Receptors, by which cells receive messages, are constructed under genetic direction, as are the molecules that direct the synthesis, storage, and secretions of the neurotransmitters and hormones. Therefore, whatever affects genetic function radiates to receptor structure and function. In turn, this coupling of molecular and receptor biology ties into work on neurological structure, physiology, and chemistry—into psychobiology, in short.

New technologies have transformed clinical practices. For example, in gynecological surgery, the carbon dioxide laser has made an enormous social impact by changing surgical procedures that once required hospitalization into procedures that can be done during office visits, with substantial savings in costs, time, and hospital resources, as well as reduced patient trauma.

There is, at the moment, a virtual explosion of biological knowledge. This may indeed be the era of biology: an era in which the innovative use of instrumentation produced from the contributions of the physical sciences—lasers, large-scale integrated circuits, and computers, for example—is merging with fundamental insights into the nature of the living cell.

The direct implication is not that chronic diseases will fade. In the next several years, however, there may emerge wholly new techniques for treating these diseases—techniques that are not simply ameliorative but penetrate to the fundamental causes of these diseases. These techniques will be highly specific, quite complex, and will require fundamental understanding for effective application.

The Pace of Technological Innovation

A 1960's study found an average 30 years' lag between basic research and technological application. Today, the lag is much shorter, as evidenced by the accelerating creation and use of new lasers, by the quick exploitation of such new scientific insights as recombinant DNA methods, by the discovery of brain peptides, and by the creation of polymetallic cluster catalysts out of surface studies.

The pace is also evident in the emergence, within the very recent past, of a new biotechnology industry principally relying on work done in the past 10 years. Similarly, the intense industrial development of very large scale integrated circuits depends on a knitting of fundamental work done almost in parallel—that work embracing materials and solid-state science, a host of new spectroscopies, and atomic and molecular physics. The character of industrial research and development in many instances has been altered by fundamental work, again much of it within the past 10 years. For example, the pharmaceutical industry has altered its approaches to designing, creating, and testing new drugs, governed by the new understanding provided by receptor biology of how signals enter and change the behavior of cells.

The implication is that we are now in an era of quickening scientific and technological change and that the two intertwine ever more closely. Opportunities are coming so fast, and competition for markets for advanced technologies is becoming so intense, that success will depend directly on the ability to create and then to exploit the new knowledge quickly.

In such an era of rapid transformation, the structures for basic research and technological development must be dynamic and must be constantly freshened by the infusion of new and highly trained scientists and engineers, by the very best instrumentation, and by unfettered communication of fundamental knowledge.

Improving Scientific and Technical Communications

The intensifying pace of scientific advance and the increasing importance of basic research to gestating new technologies combine to require that the American research system must exploit to the fullest the new communication modes now becoming available. For that reason, we discuss below new approaches to improving the communication of scientific and technical advances—electronic networks for rapid transmission of "mail" and data; growing numbers and capacities of electronic data bases, such as those of Chemical Abstracts or the National Library of Medicine; and electronic forms of publication.

The importance of these emerging communications modes to the progress of science and technology is intensified by the increasingly interdisciplinary nature of many fields of science and technology. For example, two fields described in this report—psychobiology and surface science—are generically dependent on the ability of scientists and engineers from diverse fields to interact rapidly and extensively. Progress in these fields—and, increasingly, maintenance of excellence in all fields of science and engineering—will depend on sophisticated use of the new communication modes.

It is ironic that, despite the fact that American scientists and engineers pioneer in the development and use of the latest and most sophisticated instrumentation in their experimental work, the instruments they use to exchange information have changed relatively little. With few exceptions, scientists still rely on two major and relatively traditional forms of information exchange: (1) face-to-face communication (by traveling to national or international meetings), and (2) reading scientific publications (either directly in the office or library, or by requesting the author to send a reprint). Depending upon the scientific locale and the size of the circle in which the scientist is involved, the standard sources of information may be supplemented by seminars and letter writing. However, for the most part, the information being exchanged is anywhere from months to years behind the actual state of the experimental program at the bench or the conceptual progress shared among leading members of a field.

Such continued reliance upon printed statements of progress or upon face-to-face contacts is an unnecessary impediment to the progress and communication of science and technology. Solutions for eliminating these impediments are available and could improve the communication of science substantially. These possible improvements depend upon advances that have occurred in electronic communications.

Nevertheless, a skeptic might argue that these advances in communication (perhaps viewed as just modest improvements on the telephone) will only contribute to information overloads. A major need now is to encourage a comparable advance in "smart" computer terminals through the use of programs that can digest, scan, and analyze the scientific flow of electronically stored information, filter it for each reader's self-defined profile of interests, and then condense the data. The chapter on robots has indicated the importance of the interactions between hardware and software developments for progress in automated machine capabilities. Similar extensive research and development efforts in computer language and artificial intelligence will be required to realize the full scientific and social potential of the new electronic media.

There are several implications for the nation. How can scientists and engineers be encouraged to use the new electronic modalities innovatively and effectively? What levels of support are needed? In what fields? Overall, there will be rapid changes in the communications structures in the next several years, with major impacts on the competitiveness of American science and technology. The topic needs careful examination if sound policies are to be applied.

Research-Based Technologies

The rapidity of scientific and technological advances links directly to the emergence of new research-based technologies. These are technologies that would not exist without basic research, for which the role of basic research was not to improve but to germinate. Thus, molecular beam epitaxy could not and did not exist before the perfection of new methods and insights in surface science. The 1980's will see more advanced technologies created by research. There are hints of these in this report—totally new approaches to treating major mental illnesses relying on a molecular understanding of how the brain functions; new sensory devices for the handicapped; new tactics for clinical diagnosis and surgery made possible by new lasers; new agricultural insights flowing from a deeper understanding of plant biology, and much more versatile industrial robots.

The implication is that, more than ever, basic science will be vital to technological advance and, in turn, to better productivity and enhanced economic growth. Although basic science is not inexpensive—in 1983, the federal government will provide about $6 billion for basic research out of its total federal research and development budget of $40 billion—it still is the least costly component of technological innovation. And its value in the years ahead will be multiplied as the national economy, both its manufacturing and its service sectors, is suffused by advanced technologies.

Coupling Science and Technology

Then nation needs no persuasion on the contribution of science and technology to national goals. The federal government is not only the leading patron of basic research in the United States, but also, to a significant degree, involves itself in the various phases of technological innovation—through demonstration programs, through developmental projects for military needs, and through special efforts of broad potential, such as the Very High Speed Integrated Circuit program of the Department of Defense.

Recognition is growing that basic research and advanced technology are critical to future economic growth and the ability to sell in global markets. In its "vision" for the 1980's, Japan's Ministry of International Trade and Industry calls for a "technology-based" nation, with more governmental support for research and development as a centerpiece. France is raising its investments in research to deal with its economic difficulties.

The nation will have to consider whether current policies regarding research and development are sufficient to meet present and future national requirements. Whether the topic is surface science, robotics, cell receptors, or the genetics of complex organisms, there is evidence of an increasing interdependence of basic research and technological development.

The nation may need to examine mechanisms for enhancing the symbiosis of science and technology. Basic research is conducted predominantly in the universities; much applied research and most development are carried out by industry. Overall, while industry does about 70 percent of the nation's research and development, only 4 percent of that effort goes to basic research. Although only 10 percent of all research and development is done by colleges and universities, it represents 50 percent of the nation's basic research as measured in federal obligations. Should the federal government actively catalyze the university-industry cooperation that is already occurring? Should it encourage more broad-based support for research and development? If the latter course is adopted, then where should that support go? What should be the criteria? Who will select?

Boundaries

Finally, traditional disciplinary boundaries are dissolving between the fields of science and between science and technology. As examples of this trend, consider, as described in this report, how solid-state physics has merged with materials science and with chemical engineering and computer science to produce new catalysts and microelectronic fabrication methods; how optics, solid-state physics, and cellular biology have merged in the creation of flow cytometry for analyzing cell components; and how robotics and psychobiology merge in their analysis of vision.

Fundamental studies of how a smoothly flowing fluid becomes a turbulent one devolve into work in mathematics, in physiology, in the dynamics of the atmosphere, and in galactic structure. The search to uncover the structure of cell receptors needs the recombinant DNA techniques of molecular biology. And, in turn, fundamental work in receptor biology has sparked the discovery of peptide receptors governing neurological events.

The chapter on surface science also makes the point that, increasingly, science and technology are synergistically coupled. Surface science, in its modern form, is the product of several technologies that provided high-vacuum instrumentation and tools for measuring surface events and structure; one of the results of that science is the creation of a potential new technology, molecular beam epitaxy, for building semiconducting layers 100 atoms thick, varying by one or two atoms. Molecular beam epitaxy will surely create a new generation of electronic and electrooptic devices. That advance occurred in the past 15 years, and the rapidity of the progress and application is due to the close coupling of fundamental scientific work with the development and production components of technological innovation.

In fact, instrumentation increasingly knits together science and technology—nuclear magnetic resonance, scanning electron microscopes, a panoply of lasers, new sources of synchrotron radiation, and a boggling array of other tools that are indispensable to the advances recounted in this report.

The implication of these dissolving boundaries is that they alter the question of which areas of science should have priority support. The question must be rephrased before it can be answered reasonably. Because of the strong effects that advances of knowledge in one field may have on understanding phenomena in a quite different field and the major contributions to instrumentation, technique, and methodology that flow across disciplinary boundaries, it is essential that all of the major fields of science continue at strong levels of activity and excellence. In addition to general strength, but not in substitution for it, particular "targets of opportunity" may be selected for special attention from time to time. However, in the long run, the highest priority is balanced strength and an insistence on the highest quality.

These are difficult times, and the remainder of this decade may be an era of economic stresses. The temptation is to select, to have priorities, to mark some scientific fields as critical to the nation's welfare and others as less so. There is no specific historical experience to support this. If one lesson has been learned in all of the studies of the relation of scientific knowledge to technological advancement and in turn to economic strength, it is that we will be surprised. We cannot choose selective excellence in science.

Part 5

THE ACADEMY FIVE YEAR OUTLOOK REPORTS

Each of the studies performed by the National Academy of Sciences in support of the Five Year Outlook reports have been published separately by a commercial publisher, W. H. Freeman and Company of San Francisco.

In each case the study was published some months prior to the submission of the official Outlook report to the Congress.

The portions of these volumes reproduced in this part show, in addition to the substantive content, the large number of scientists, engineers and others who contributed to the study.

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FIRST ACADEMY REPORT

Science and Technology

A FIVE-YEAR OUTLOOK

Published in collaboration with the National Academy of Sciences by

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Preface

> The National Science and Technology Policy, Organization, and Priorities Act of 1976 directed the Office of Science and Technology Policy to prepare periodically a Five-Year Outlook on Science and Technology. Specifically, the Congress asked to be informed of conditions that might warrant special attention within the next five years, involving—
>
> • Current and emerging problems of national significance that are identified through scientific research, or in which scientific or technical considerations are of major significance; and
>
> • Opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make a significant contribution to the resolution of these problems. . . .

A reorganization of the Executive Office of the President in 1977 transferred the responsibility for a five-year outlook to the National Science Foundation. In 1978, the Foundation asked the National Academy of Sciences to assist in the preparation of the Five-Year Outlook by providing a report describing the current state of significant research areas and pointing out issues within those areas that could be of special concern within the five-year period. After preliminary consideration of the intent and content of the report, the Academy began its work under contract in August 1978, with a commitment to deliver a manuscript to the Foundation by the end of March 1979.

With the advice of the President's Science Advisor and the Director of the National Science Foundation, the Academy—acting principally through the National Research Council, in collaboration with the National

Academy of Engineering and the Institute of Medicine—selected a number of areas in science and technology to be included in the first outlook report. Ralph E. Gomory was appointed Study Chairman. In turn, a steering committee was constituted, its membership composed of those principally responsible for the preparation of the chapters of the report.

A two-tier review procedure was also established: a review of initial drafts by members of the National Academy of Sciences, the Institute of Medicine, the National Academy of Engineering, and units of the National Research Council; and a final review, prior to release of the report to the National Science Foundation, by the Governing Board of the National Research Council.

This report was submitted to the National Science Foundation on March 30, 1979. It is anticipated that when the Foundation transmits the formal five-year outlook to the Congress it will include—in addition to this Academy report—a set of papers prepared by selected federal agencies, papers commissioned by the Foundation on selected, policy-related topics, and a summary and analysis. Present plans call for the process to be repeated biennially.

The present report is not a comprehensive statement on the status of all science and technology in the United States. Nor is it a statement of the relative merits or priorities among the large family of disciplines and activities that comprise science and technology. The sweep of the scientific and technological enterprise, as well as the short time allotted for the preparation of this report, compelled a selective approach. Major areas—such as mathematics, economics, synthetic chemistry, and land use and water resources; the technologies of the transportation, buildings, and textile industries; and the general question of industrial technology and innovation, to name but some—are not explicitly discussed.

The chapters that follow do, however, illustrate the present vitality and direction of much of American science and technology. They should enable appreciation of both the substance of science and technology and its interaction with the formulation of public policy. The 11 chapters are divided into 4 units: science, technology, topics specific to the United States, and scientific institutions. The contents and arrangement of the chapters are given in the Contents. An index is also provided.

Each chapter is followed by a short outlook emphasizing five-year trends. These outlook statements are brief; the bases for the trends there noted are to be found in the chapters themselves. A section entitled "Observations" follows the Contents and provides some general thoughts on American science and technology.

The projections for various areas of science and technology derive from assessments of their current status, the work being done, and the evident trends. That approach is tempered by specifics. Since technological produ[illegible] available five years from now should be at the design [illegible] be surer of the five-year prediction for a given technology, [illegible]s of new forms of plastics to replace metals in car manufacture [illegible]ihood that new commercial coal conversion processes will be in place. In basic science, however, the more reasonable approach is to assess current work and its general directions, for example, pointing out the considerable recent progress made in understanding the role of membranes of living cells or the steady addition to the list of precursory phenomena associated with earthquakes.

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SECOND ACADEMY REPORT

Outlook for Science and Technology

THE NEXT FIVE YEARS

A Report of the
National Research Council

Published in collaboration with the National Academy of Sciences by

W. H. FREEMAN AND COMPANY
SAN FRANCISCO

Study Chairman

Frederick Seitz, The Rockefeller University

Vice Chairman

John S. Coleman, Arlington, Virginia

Steering Committee

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John E. Cantlon, Michigan State University
W. Dale Compton, Ford Motor Company
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William R. Hewlett, Hewlett-Packard Company
Mark Kac, The Rockefeller University
Nathan Keyfitz, Harvard University, Ohio State University
John P. Longwell, Massachusetts Institute of Technology
Gordon H. Orians, University of Washington, Seattle
I. M. Singer, University of California, Berkeley
Gary Strobel, Montana State University
Gilbert F. White, University of Colorado, Boulder

Chapter Coordinators and Contributing Authors

1 **The Demographic State of the World**
Nathan Keyfitz, Harvard University, Ohio State University

W. Parker Mauldin, The Rockefeller Foundation
William Petersen, Carmel, California
Samuel H. Preston, University of Pennsylvania
Ronald Ridker, Resources for the Future

2 **On Some Major Human Diseases**
Philip Handler, National Academy of Sciences

Charles L. Christian, Hospital for Special Surgery, New York
Oscar B. Crofford, Vanderbilt University
Emil Frei, III, Sidney Farber Cancer Institute
H. S. Kaplan, Stanford University Medical Center

Daniel J. McCarty, Medical College of Wisconsin
Russell Ross, University of Washington School of Medicine, Seattle
Harvey Wolinsky, Albert Einstein College of Medicine

3 **Directions in Nutrition Research**
Alfred E. Harper, University of Wisconsin

W. R. Beisel, U.S. Army Medical Research Institute for Infectious Diseases
Maurice R. Bennick, Michigan State University
Lavelle M. Henderson, University of Minnesota
R. E. Shank, Washington University School of Medicine, St. Louis
Richard J. Wurtman, Massachusetts Institute of Technology

4 **The Science of Cognition**
William K. Estes, Harvard University

Richard M. Shiffrin, Indiana University
Herbert A. Simon, Carnegie-Mellon University
Edward E. Smith, Bolt-Beranek & Newman

5 **Ecology and Systematics**
Gordon H. Orians, University of Washington, Seattle

Eric L. Charnov, University of Utah
W. T. Edmondson, University of Washington, Seattle
Gene Likens, Cornell University
Robert T. Paine, University of Washington, Seattle
Peter H. Raven, Missouri Botanical Garden
David Schindler, Canadian Limnological Laboratory, Winnipeg
Otto Solbrig, Harvard University

6 **Plant Disease**
Gary Strobel and Donald E. Mathre, Montana State University

7 **Water Resources**
Gilbert White, University of Colorado, Boulder

John D. Bredehoeft, U.S. Geological Survey
John Cairns, Jr., Virginia Polytechnic Institute
Russell Christman, University of North Carolina
Allen V. Kneese, Resources for the Future
Daniel A. Okun, University of North Carolina
Theodore M. Schad, Commission on Natural Resources of the National Research Council

8 **Radioactive Waste Management**
Merril Eisenbud, New York University Medical Center

Members and Staff of the Committee on Radioactive Waste Management of the National Research Council

9 **Sun and Earth**
Herbert Friedman, National Research Council

10 **The Science of Macromolecules**
Paul J. Flory, Stanford University

Harry R. Allcock, Pennsylvania State University
Henryk Eisenberg, Weizmann Institute of Science, Rehovot, Israel
Richard J. Feldmann, National Institutes of Health
Do Yeung Yoon, IBM Research Laboratory, San Jose

11 **Chemical Synthesis of New Materials**
Theodore L. Cairns, Greenville, Delaware

F. A. L. Anet, University of California, Los Angeles
Neil Bartlett, University of California, Berkeley
Virgil Boekelheide, University of Oregon
Ronald Breslow, Columbia University
D. A. Evans, California Institute of Technology
R. A. Laudise, Bell Laboratories
David A. Pensak, E. I. du Pont de Nemours & Company, Inc.
Barry M. Trost, University of Wisconsin
Lewis H. Sarett, Merck & Company, Inc.
Nicholas J. Turro, Columbia University

12 **On Some Recent Developments in Mathematics**
Mark Kac, The Rockefeller University

Jonathan L. Alperin, University of Chicago
Daniel I. A. Cohen, The Rockefeller University
Martin Davis, New York University
I. M. Singer, University of California, Berkeley
Shing-Tung Yau, Institute for Advanced Studies, Princeton

13 **Research in Europe and the United States**
Albert M. Clogston, Bell Laboratories

Robert McC. Adams, Oriental Institute, University of Chicago
Charles V. Kidd, George Washington University
Bruce L. R. Smith, The Brookings Institution
I. M. Singer, University of California, Berkeley

14 **Research in Industry**
William R. Hewlett, Hewlett-Packard Company

Paul Chenea, General Motors Corporation
Edwin Mansfield, University of Pennsylvania
Robert E. Naylor, E. I. du Pont de Nemours & Company, Inc.
Kenneth Poole, Bell Laboratories
John E. Steiner, The Boeing Company
Peter Stewart, General Electric Company
P. Roy Vagelos, Merck, Sharpe & Dohme Research Laboratories

15 **Fuel Science and Technology**
John P. Longwell, Massachusetts Institute of Technology

16 **Issues in Transportation**
W. Dale Compton, Ford Motor Company

John J. Fearnsides, The MITRE Corporation
Oscar Fisch, Ohio State University
Howard L. Gauthier, Ohio State University
William J. Harris, Association of American Railroads
Gerald Kayten, National Aeronautics and Space Administration

17 **Prospects for New Technologies**
Frederick Seitz, The Rockefeller University

Paul Barton, U.S. Geological Survey
Herbert Friedman, National Research Council
Theodore Geballe, Stanford University
Robert A. Huggins, Stanford University
Courtland Perkins, National Academy of Engineering
Jacob Schwartz, New York University
Arthur C. Upton, New York University Medical Center
Norton Zinder, The Rockefeller University

Editorial Consultants

George A. W. Boehm, New York, New York
Duncan M. Brown, National Research Council
Elizabeth W. Fisher, Washington, D.C.
Gregg Forte, American Geophysical Union
Ruth B. Haas, Resources for the Future
Robert R. Hume, National Research Council
Robert M. Joyce, Hockessin, Delaware
Susan McGrath, Washington, D.C.

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Preface

The first Five-Year Outlook for Science and Technology prepared by the National Research Council was delivered to the National Science Foundation in March 1979. This second Outlook follows the general pattern of that document in portraying selected facets of science and technology as they pertain to the disciplines themselves—from solar-terrestrial physics to cognition to mathematics—and as they affect national concerns—from water resources to the management of radioactive wastes to transportation.

The immediate purpose of this and the preceding report is to aid the National Science Foundation in responding to the Congressional request, as expressed in the National Science and Technology Policy, Organization, and Priorities Act of 1976, that Congress and the people of the United States be informed in a continuing manner of conditions which might warrant special attention within the next five years, particularly those that involve:

- Current and emerging problems of national significance that are identified through scientific research, or in which scientific and technical considerations are of major consequence.
- Opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make important contributions to the resolution of these problems.

Frederick Seitz served as the study chairman, assisted by a resident vice chairman and a steering committee whose membership was derived largely from those responsible for the preparation of individual chapters of the report. The design of this report is premised on the desire to build on the contents of the first Outlook and to include several of the vital areas not dealt with in the first report. Therefore, to the general discussion in the first report on energy has been added a report on the management of radioactive wastes; similarly, the considerable discussion of reductionist biology in the first is joined by ecology and systematics in the second; that of the structure of matter by solar-terrestrial physics; that of U.S. demography by world demography; that of a description of the health care system by a report on biomedical research on a limited list of major afflictions. In like manner, some of the vital areas not reviewed in the first Outlook are now in the second, while others have been deferred. This report, thus, includes chapters on chemistry and mathematics, but, for lack of space, does not deal with, for example, economic science and agricultural research. These and other topics will be considered in future reports on the Five-Year Outlook for Science and Technology.

Like the first report, this second Outlook has undergone several formal reviews. Its early contents were evaluated and given mid-course corrections by the steering committee. Each chapter was subsequently reviewed in detail and revised in response to comments from those expert in its subject. In addition, the Governing Board of the National Research Council reviewed the entire manuscript prior to its final revision before delivery to the National Science Foundation on March 31, 1981.

The names in this volume of those who wrote it and those who reviewed it testify that its preparation engaged a wide spectrum of the very best of American scientists and engineers. That this volume exists at all is due directly to the knowledge, thought, and care they brought to its preparation.

THE SECOND FIVE-YEAR OUTLOOK

As indicated in the Preface, the present volume and the first Five-Year Outlook report should be regarded as successive stages, with this volume complementing its predecessor. Thus, the presentations of Planet Earth, The Living State, and The Structure of Matter in the first volume are followed now by presentations on Sun and Earth, The Science of Cognition, Chemical Synthesis of New Materials, and Some Recent Developments in Mathematics. The Demography of the United States in the first volume is succeeded here by The Demographic State of the World. A general treatment of the Health of the American People is followed up by a more detailed consideration of Some Major Human Diseases and of Directions in Nutrition Research; to appreciate these fully, it may be necessary to refer to some of the material in the earlier presentation of The Living State. To the earlier chapters on Computers and Communications and on Materials are added chapters on Prospects for New Technologies, Research in Industry, and Issues in Transportation. A general treatment of problems of Energy is supplemented by treatments of Fuel Science and Technology and of Radioactive Waste Management. Toxic Substances in the Environment is paralleled by treatments of Water Resources, Ecology and Systematics, and Plant Disease. Finally, the summary of Academic Science and Graduate Education is followed here by a comparison of the modes of support and conduct of research in Europe with those in the United States. It must be recognized, however, that large elements both of the scientific endeavor and of American technological enterprise remain untreated in these two volumes. It is our hope that they will be considered in future Outlook reports.

THIRD ACADEMY REPORT

Frontiers in Science and Technology

A SELECTED OUTLOOK

A Report by the
Committee on Science, Engineering, and Public Policy
of the
National Academy of Sciences
National Academy of Engineering
Institute of Medicine

W. H. FREEMAN AND COMPANY
New York/San Francisco

Preface

This volume, entitled *Frontiers in Science and Technology: A Selected Outlook*, is the third in a series of reports on the five-year outlook for science and technology. The volume was prepared under the chairmanship of Floyd E. Bloom, of The Salk Institute, and the aegis of the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The Committee selected the topics, arranged for peer review of each chapter, and contributed to the analysis of the wider implications flowing out of these fields. The Committee also reviewed the entire report and is solely responsible for its contents.

The outlook reports were called for in the National Science and Technology Policy, Organization, and Priorities Act of 1976. A subsequent reorganization of the Executive Office of the President assigned responsibility for preparing the outlooks to the National Science Foundation. This volume was prepared by COSEPUP, on behalf of the National Academies and the Institute of Medicine, at the request of the Foundation.

As expressed in the Act, the purposes of the outlook reports are to inform the Congress of:

- Current and emerging problems of national significance that are identified through scientific research, or in which scientific and technical considerations are of major consequence.
- Opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make important contributions to resolving these problems.

The material contained in this report is directly responsive to this charge. It reports on eight areas of inquiry that have had and promise to have important societal impacts, and which reflect the diversity, interdependence, and excitement of contemporary science and technology. The study also contains as part of the introduction a discussion of implications for the national agenda of work in these eight areas, a feature not present in earlier outlooks. By including such a discussion, COSEPUP hopes to meet more fully the congressional intent in the legislation calling for the five-year outlooks.

This volume exists because of the efforts of many individuals. James D. Ebert, Vice President of the National Academy of Sciences, was instrumental in planning it. Primary thanks for producing this report are due to the authors and reviewers, to Philip Yeager, who contributed to the discussion of implications, and, most especially, to Floyd Bloom, the Outlook's tireless and dedicated chairman. They have produced an important and readable volume which we commend to your attention.

March 1983

George M. Low, Chairman
Committee on Science, Engineering,
and Public Policy

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Introduction: Science, Technology, and the National Agenda

Floyd E. Bloom
Study Chairman

Director,
Arthur V. Davis Center
for Behavioral Neurobiology,
The Salk Institute

Frontiers in Science and Technology: A Selected Outlook is the third such canvass of the prospects for several fields of science and technology. All three reports were prepared in response to a congressional request that the five-year outlooks for science and technology be examined periodically. Specifically, the Congress asked that such outlooks identify national problems to which science and technology pertain and that they outline specific opportunities and constraints in their use. The request was—and continues to be—a daunting one, owing partly to the rapidity of scientific and technological progress and to the evolution of congressional priorities. The obvious need to select certain fields of science and engineering for this analysis—and even to select specific topics within each field—simply magnifies the difficulties.

Yet, we believe that the contents of this volume, reporting on current and future work in eight growth points of American science and technology, respond directly to the congressional aim to draw more fully the relation of science and technology to the very large and kaleidoscopic agenda with which the nation must deal.

Perhaps the most important theme that emerges from this volume is the remarkable fertility of American science and technology. New knowledge has provided new ways for understanding diseases. Such fundamental research areas as surface physics and turbulence theory have yielded new technologies and new controls for ancient problems. Assuming real growth in research support, the United States can ex-

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The study chairman gratefully acknowledges the critical collaboration of Norman Metzger, chief editor of the Outlook Reports, in the preparation of this report.

pect to remain at the forefront of virtually all scientific frontiers in the 1980's and beyond.

IMPLICATIONS—FROM GENETICS TO ROBOTICS

Each chapter harbors implications affecting the national agenda. These are indicated briefly below, albeit with the suggestion that either the summaries accompanying each chapter or, more profitably, the full chapters themselves also be read.

The Genetic Program of Complex Organisms (Chapter 1)

Until the 1970's, direct study of the genes of organisms more complicated than bacteria and viruses was constrained by lack of experimental methods. With the advent of recombinant DNA and other methods, it became possible to study directly the genes of plants and animals, including those of man. It was then feasible to isolate genes responsible for particular functions, to examine their structure, and to decipher the controls on their operation.

We are in part what our genes make us, and therefore these genetic discoveries of the last 10 years will have global effects—in new insights into how an organism develops from a single fertilized egg, how it grows, and how it ages. We are also gaining new insights into some fundamental aspects of cancer; for example, rearrangements in DNA structure may be common to diverse causes of tumors, including chemical carcinogens and viruses. This work supports a shift in emphasis from the cure to the prevention of cancer. Further, we are now moving to a new level in understanding many inheritable diseases, in mitigating their effects, and in finding new methods of treating some of these once hopeless conditions.

Commercially, the new understanding of gene structure—and the research and technology that made it possible—has led already to new manufacturing techniques for creating otherwise difficult-to-make, often unavailable, and usually expensive molecules. These include insulin for treating human diabetes without the risk of immunological side effects, growth hormones for the prevention of growth abnormalities, and interferon for the possible treatment of certain cancers.

In all, the past decade in molecular biology has been marked by accomplishment, by the creation and maturation of new techniques, and by a sharper definition of questions to be probed. The next five years will provide answers and generate more questions. Also, the new knowledge will yield imaginative solutions to longstanding problems. New and better drugs and vaccines will be manufactured; new and improved plants may be developed and the yields of existing plants raised; and the diagnoses of diseases will be improved and new treatments of some of these diseases emplaced.

The Molecular and Genetic Technology of Plants (Chapter 2)

Some plants, such as carrots, will grow readily from single cells; others, such as soybeans, will not. No one knows why. This reflects an ignorance at the fundamental level of the regulation and structure of plant genes and of the factors governing the growth of plants. Gaining such knowledge has the potential to quicken the rate of breeding new plants, to raise yields, and to extend agriculture to marginal lands.

Understanding of the genetics of plants now lags that of animal genetics, so the potential remains uncertain but still enormous. Thus, whether improved understanding of plant genetics will yield new plants useful as crops remains speculation. However, the rapid pace of work in the field, marked by increasing university–industry cooperation, will surely aid in breeding more useful agricultural plants. Improved disease resistance, salt and drought tolerance, and more efficient photosynthesis are all targets of a heightened knowledge of plant genetics and the ability to manipulate it.

We may learn how to prompt seeds to accumulate more protein of a higher quality, to increase the efficiency of nitrate use, and to control plant growth and development. As our knowledge of plant genes enlarges, so will our capacity for finding faster and less expensive ways to breed crops suited to changing demands and conditions.

Cell Receptors for Hormones and Neurotransmitters (Chapter 3)

The cells of an animal or a plant must function in an integrated manner in order for the organism to survive and reproduce. In turn, integration depends upon the ability of the cells to recognize and respond to such chemical signals as hormones and neurotransmitters. Recognition and response rely on special molecules or structures in cells, called receptors. As in the case of molecular genetics, the last decade has been marked by a rapidly growing understanding of what receptors do and how they work.

In brief, receptors enable cells to react to chemical instructions from other cells. If the receptors do not work as they should or are missing, the cell malfunctions; if receptors are occupied by certain drugs or by autoantibodies to them, natural signals may be ignored. The growing knowledge of receptors, particularly since the mid-1970's, is unfolding a succession of applications and insights for a host of possible "receptor diseases" whose causes were previously unsuspected.

Further, receptor research has led to rapid and highly specific methods of following the responses to drugs of healthy and diseased cells. The mechanisms by which cells are able to regulate their responsiveness have been demonstrated. Better guides in treating human breast cancers, which may illuminate approaches to other hormonally responsive cancers, have been developed. A more detailed knowledge of how insulin works has refined our knowledge of various forms of diabetes.

In the next several years, the exact mechanisms of receptors for specific chemical messengers will become better understood. With that, our knowledge at a molecular level of how a given hormone or neurotransmitter actually exerts its effects will be enhanced.

Such knowledge inevitably will be applied to the design of drugs; that is, to finding agents that modulate, enhance, or block the actions of selected chemical messengers at their receptors. We may expect, therefore, a new generation of drugs which are much more specific in their actions and whose pharmacology will be understood at a molecular level. Similarly, approaches to diagnosis, interpreting disease symptoms, and designing treatment strategies will be altered by our heightened awareness of how cells "talk" to each other.

Psychobiology (Chapter 4)

The nerve cells of the brain communicate by using chemical and electrical signals to process information through the complex pathways by which we act and think. The search for ways to understand the physical basis of behavior and mind is continuous, difficult, and incrementally successful. A spectrum of implications is emerging from research on the brain. These include improved understanding of psychiatric and neurological diseases, the physical basis of learning, and the effects of aging. Through the use of animals in research, we now have better knowledge of the behavioral abnormalities underlying certain aspects of depression and anxiety.

There has been substantial progress in understanding some forms of deafness, suggesting what might be done about them. Advances in sensory physiology have led to electronic devices that, in a limited way, can substitute for injured eyes and ears, as well as alleviate some forms of chronic pain. Prenatal and perinatal studies are clarifying the causes of some forms of brain damage, while postnatal studies of brain development will aid in improving the education of children and will help them to reach their full capacities.

Surface Science and Its Applications (Chapter 5)

Surface science is concerned with the first few atomic layers at the surfaces of solids and examines the effects of those layers on the rest of the solid and on other materials. All solids, natural or synthetic, have surfaces, and the character of those surfaces—their structure, their electronic nature, and the atoms that they are composed of—can influence the physical and chemical behavior of the entire solid and the interaction of the solid with other atoms and molecules and with external radiation.

With the very rapid miniaturization of electronic devices, the proportion of atoms on the surfaces of integrated circuits—and hence their importance—has increased. Atoms adhering to surfaces can form "surface molecules" having, in some cases, structures not found in the gas phase. Thus, the study of chemistry at surfaces provides new insights into the interactions of molecules—events that, despite their scientific and economic importance, are still not well understood. The chemical and petroleum-refining industries rely on catalysts that speed particular reactions; an improved understanding through surface studies of how catalysts work will translate into more economic chemical processes and also into fewer side products and, hence, fewer environmental problems.

Surface studies may lead to improved corrosion-resistant materials and corrosion-preventing coatings. Surface analytical techniques are improving our knowledge of embrittlement and structural failures. The field ramifies into unlikely areas—for example, into land management, since much of soil chemistry is really colloid chemistry, which in turn is a branch of surface science dealing with small particles at a solid-liquid surface.

Turbulence in Fluids (Chapter 6)

Moving fluids tend toward turbulence, whether they are air, blood, ocean water, the aerosols of clouds, the oil flowing in pipelines, the lithosphere of drifting continents, or galaxies. Turbulence is disordered fluid flow, and understanding what initiates and maintains it is essential to better prediction and control of turbulent events.

As a practical matter, analysis of turbulence is limited to statistical approximations of what happens in turbulent flow, as distinct from what actually happens. There are now negligibly few ways of predicting turbulence quantitatively. The result is an inability to generalize—to use with confidence—the studies of turbulence associated with a particular turbine design in designing a different type of turbine. Work under way is providing new insights into turbulence that promise deeper understanding of universally applicable features of turbulent events.

Studies of turbulence may lead to improved design of axial compressors and pumps, military and civilian aircraft, chemical reactors and mixers, and more accurate prediction of ocean currents and weather patterns. Finally, new insights into the origins of disorder in natural systems may contribute not only to understanding fluid turbulence but also to model building in economics and ecology.

Lasers (Chapter 7)

Lasers are devices in which atoms, molecules, or ions are made to radiate at frequencies corresponding to separations between discrete energy levels. The product is light of essentially a single wavelength and phase—coherent light. Such light is monochromatic, or of one color; highly directional, emerging as a narrow and focused beam; and intense. The wavelength range of laser light has widened considerably in the 25 years since the laser was invented, and many novel applications have emerged. In the next several years, both the uses of lasers and their capacities will expand. Lasers are remarkable, not only for what they have done but for what they now seem on the verge of doing in a range of important applications, extending from lightwave communications to new medical surgeries and from diagnostics to separating uranium isotopes.

Laser science and technology are now driven by a reverberating dance between device physics and need: an evident application spurring the development of a suitable laser, and a new laser prompting new uses. Examples include flow cytometry, that is, the separation of cells according to their size, shape, and reflective properties, and their further sorting according to, for example, their shape and DNA content—all within minutes. Another illustration is the mode-locked laser which enables scientists to observe events occurring in trillionths of seconds, such as the chemical changes in a chlorophyll molecule triggered by light quanta, leading in turn to an improved understanding of the initial stages of photosynthesis.

The Next Generation of Robots (Chapter 8)

Robots are computer-controlled devices that reproduce human senses, manipulations, and motions well enough to do useful work. They are now being installed in manufacturing plants and, in the next several years, major expansion of their uses and capacities will occur.

Today's robots are usually sedentary, stand-alone arms, with limited precision, little sensory capability, and little if any capacity for dealing with the unexpected; thus, they can work effectively only in highly structured industrial settings.

However, these limitations are being eroded by the application of technical expertise gathered in the past 10 years. Thus, new computer languages will enable quicker, more precise communication between people and robots. New sensors will enable robots to see, to feel, to walk, and to recognize commands. Systems integrating these newly endowed traits are being developed, leading in time to a new generation of robots that can deal with disorder—that can, for example, pick a specific piece out of a bin of jumbled parts. Eventually, robots will grow in numbers and in capacities, and will become a major factor in industrial activity and change.

WIDER IMPLICATIONS

The broad themes derived from these chapters can now be discussed more extensively. They include:

- Changing perspectives on health care.
- The faster pace of technological innovation.
- The importance to scientific and engineering progress of the effective use of new communications technologies.
- The emergence of research-based technologies.
- The need to examine federal policies in regard to research and development considered as a whole.
- The quickening dissolution of the traditional boundaries between the sciences and between science and technology.

Health Care

The nation will face the escalating costs of treating chronic diseases that increasingly incapacitate and kill Americans—heart diseases, cancers, arthritis and related disorders, metabolic diseases, and a wide and complex array of psychiatric and neurological diseases.

These diseases—successors to such acute illnesses as pneumonia, tuberculosis, infantile diarrhea, syphilis, and typhoid fever as leading killers—have causes that remain unknown and develop in patterns not sharp enough to enable invariably successful intervention. Much of the care applied to them is supportive clinical management—costly "halfway technologies."

Yet, as several chapters of this report suggest, we now have new windows into many of these disorders. The unraveling of how messages are transmitted from outside to inside the cell—and what happens when that communication system is disrupted—is in turn clarifying the nature of an increasing number of diseases—hormonal illnesses, such as diabetes, and neurological diseases, such as myasthenia gravis.

Receptors, by which cells receive messages, are constructed under genetic direction, as are the molecules that direct the synthesis, storage, and secretions of the neurotransmitters and hormones. Therefore, whatever affects genetic function radiates to receptor structure and function. In turn, this coupling of molecular and receptor biology ties into work on neurological structure, physiology, and chemistry—into psychobiology, in short.

New technologies have transformed clinical practices. For example, in gynecological surgery, the carbon dioxide laser has made an enormous social impact by changing surgical procedures that once required hospitalization into procedures that can be done during office visits, with substantial savings in costs, time, and hospital resources, as well as reduced patient trauma.

There is, at the moment, a virtual explosion of biological knowledge. This may indeed be the era of biology: an era in which the innovative use of instrumentation produced from the contributions of the physical sciences—lasers, large-scale integrated circuits, and computers, for example—is merging with fundamental insights into the nature of the living cell.

The direct implication is not that chronic diseases will fade. In the next several years, however, there may emerge wholly new techniques for treating these diseases—techniques that are not simply ameliorative but penetrate to the fundamental causes of these diseases. These techniques will be highly specific, quite complex, and will require fundamental understanding for effective application.

The Pace of Technological Innovation

A 1960's study found an average 30 years' lag between basic research and technological application. Today, the lag is much shorter, as evidenced by the accelerating creation and use of new lasers, by the quick exploitation of such new scientific insights as recombinant DNA methods, by the discovery of brain peptides, and by the creation of polymetallic cluster catalysts out of surface studies.

The pace is also evident in the emergence, within the very recent past, of a new biotechnology industry principally relying on work done in the past 10 years. Similarly, the intense industrial development of very large scale integrated circuits depends on a knitting of fundamental work done almost in parallel—that work embracing materials and solid-state science, a host of new spectroscopies, and atomic and molecular physics. The character of industrial research and development in many instances has been altered by fundamental work, again much of it within the past 10 years. For example, the pharmaceutical industry has altered its approaches to designing, creating, and testing new drugs, governed by the new understanding provided by receptor biology of how signals enter and change the behavior of cells.

The implication is that we are now in an era of quickening scientific and technological change and that the two intertwine ever more closely. Opportunities are coming so fast, and competition for markets for advanced technologies is becoming so intense, that success will depend directly on the ability to create and then to exploit the new knowledge quickly.

In such an era of rapid transformation, the structures for basic research and technological development must be dynamic and must be constantly freshened by the infusion of new and highly trained scientists and engineers, by the very best instrumentation, and by unfettered communication of fundamental knowledge.

Improving Scientific and Technical Communications

The intensifying pace of scientific advance and the increasing importance of basic research to gestating new technologies combine to require that the American research system must exploit to the fullest the new communication modes now becoming available. For that reason, we discuss below some new approaches to improving the communication of scientific and technical advances—electronic networks for rapid transmission of "mail" and data; growing numbers and capacities of electronic data bases, such as those of Chemical Abstracts or the National Library of Medicine, and electronic forms of rapid publication.

The importance of these emerging communications modes to the progress of science and technology is intensified by the increasingly interdisciplinary nature of many fields of science and technology. For example, two fields described in this report—psychobiology and surface science—are generically dependent on the ability of scientists and engineers from diverse fields to interact rapidly and extensively. Progress in these fields—and, increasingly, maintenance of excellence in all fields of science and engineering—will depend on sophisticated use of the new communication modes.

It is ironic that, despite the fact that American scientists and engineers pioneer in the development and use of the latest and most sophisticated instrumentation in their experimental work, the instruments they use to exchange information have changed relatively little. With few exceptions, scientists still rely on two major and relatively traditional forms of information exchange: (1) face-to-face communication (by traveling to national or international meetings), and (2) reading scientific publications (either directly in the office or library, or by requesting the author to send a reprint). Depending upon the scientific locale and the size of the circle in which the scientist is involved, the standard sources of information may be supplemented by seminars and letter writing. However, for the most part, the information being exchanged is anywhere from months to years behind the actual state of the experimental program at the beach or the conceptual progress shared among leading members of a field.

Such continued reliance upon printed statements of progress or upon face-to-face contacts is an unnecessary impediment to the progress and communication of science and technology. Solutions for eliminating these impediments are available and could improve the communication of science substantially. These possible improvements depend upon advances that have occurred in electronic communications.

Nevertheless, a skeptic might argue that these advances in communication (perhaps viewed as just modest improvements on the telephone) will only contribute to information overloads. A major need now is to encourage a comparable advance in "smart" computer terminals through the use of programs that can digest, scan, and analyze the scientific flow of electronically stored information, filter it for each reader's self-defined profile of interests, and then condense the data. The chapter on robots has indicated the importance of the interactions between hardware and software developments for progress in automated machine capabilities. Similar extensive research and development efforts in computer language and artificial intelligence will be required to realize the full scientific and social potential of the new electronic media.

There are several implications for the nation. How can scientists and engineers be encouraged to use the new electronic modalities innovatively and effectively? What levels of support are needed? In what fields? Overall, there will be rapid changes in the communications structures in the next several years, with major impacts on the competitiveness of American science and technology. The topic needs careful examination if sound policies are to be applied.

Research-Based Technologies

The rapidity of scientific and technological advances links directly to the emergence of new research-based technologies. These are technologies that would not exist without basic research, for which the role of basic research was not to improve but to germinate. Thus, molecular beam epitaxy could not and did not exist before the perfection of new methods and insights in surface science. The 1980's will see more advanced technologies created by research. There are hints of these in this report—totally new approaches to treating major mental illnesses relying on a molecular understanding of how the brain functions; new sensory devices for the handicapped; new tactics for clinical diagnosis and surgery made possible by new lasers; new agricultural insights flowing from a deeper understanding of plant biology, and much more versatile industrial robots.

The implication is that, more than ever, basic science will be vital to technological advance and, in turn, to better productivity and enhanced economic growth. Although basic science is not inexpensive—in 1983, the federal government will provide about $6 billion for basic research out of its total federal research and development budget of $40 billion—it still is the least costly component of technological innovation. And its value in the years ahead will be multiplied as the national economy, both its manufacturing and service sectors, is suffused by advanced technologies.

Coupling Science and Technology

The nation needs no persuasion on the contribution of science and technology to its goals. The federal government is not only the leading patron of basic research in the United States, but also, to a significant degree, involves itself in the various phases of technological innovation—through demonstration programs, through developmental projects for military needs, and through special efforts of broad potential, such as the Very High Speed Integrated Circuit program of the Department of Defense.

Recognition is growing that basic research and advanced technology are critical to future economic growth and the ability to sell in global markets. In its "vision" for the 1980's, Japan's Ministry of International Trade and Industry calls for a "technology-based" nation, with more governmental support for research and development as a centerpiece. France is raising its investments in research to deal with its economic difficulties.

The nation will have to consider whether current policies regarding research and development are sufficient to meet present and future national requirements. Whether the topic is surface science, robotics, cell receptors, or the genetics of complex organisms, there is evidence of an increasing interdependence of basic research and technological development.

The nation may need to examine mechanisms for enhancing the symbiosis of science and technology. Basic research is conducted predominantly in the universities; much applied research and most development are carried out by industry. Overall, while industry does about 70 percent of the nation's research and development, only 4 percent of that effort goes to basic research. Although only 10 percent of all research and development is done by colleges and universities, it represents 50 percent of the nation's basic research as measured in federal obligations. Should the federal government actively catalyze the university–industry cooperation that is already occurring? Should it encourage more broad-based support for research and development? If the latter course is adopted, then where should that support go? What should be the criteria? Who will select?

Boundaries

Finally, traditional disciplinary boundaries are dissolving between the fields of science and between science and technology. As examples of this trend, consider, as described in this report, how solid-state physics has merged with materials science and with chemical engineering and computer science to produce new catalysts and microelectronic fabrication methods; how optics, solid-state physics, and cellular biology have merged in the creation of flow cytometry for analyzing cell components; and how robotics and psychobiology merge in their analysis of vision.

Fundamental studies of how a smoothly flowing fluid becomes a turbulent one devolve into work in mathematics, in physiology, in the dynamics of the atmosphere, and in galactic structure. The search to uncover the structure of cell receptors needs the recombinant DNA techniques of molecular biology. And, in turn, fundamental work in receptor biology has sparked the discovery of peptide receptors governing neurological events.

The chapter on surface science also makes the point that, increasingly, science and technology are synergistically coupled. Surface science, in its modern form, is the product of several technologies that provided high-vacuum instrumentation and tools for measuring surface events and structure; one of the results of that science is the creation of a potential new technology, molecular beam epitaxy, for building semiconducting layers 100 atoms thick, varying by one or two atoms. Molecular beam epitaxy will surely create a new generation of electronic and electrooptic devices. That advance occurred in the past 15 years, and the rapidity of the progress and application is due to the close coupling of fundamental scientific work with the development and production components of technological innovation.

In fact, instrumentation increasingly knits together science and technology—nuclear magnetic resonance, scanning electron microscopes, a panoply of lasers, new sources of synchrotron radiation, and a boggling array of other tools that are indispensable to the advances recounted in this report.

The implication of these dissolving boundaries is that they alter the question of which areas of science should have priority support. The question must be rephrased before it can be answered reasonably. Because of the strong effects that advances of knowledge in one field may have on understanding phenomena in a quite different field and the major contributions to instrumentation, technique, and methodology that flow across disciplinary boundaries, it is essential that all of the major fields of science continue at strong levels of activity and excellence. In addition to general strength, but not in substitution for it, particular "targets of opportunity" may be selected for special attention from time to time. However, in the long run, the highest priority is balanced strength and an insistence on the highest quality.

These are difficult times, and the remainder of this decade may be an era of economic stresses. The temptation is to select, to have priorities, to mark some scientific fields as critical to the nation's welfare and others as less so. There is no specific historical experience to support this. If one lesson has been learned in all of the studies of the relation of scientific knowledge to technological advancement and in turn to economic strength, it is that we will be surprised. We cannot choose selective excellence in science.

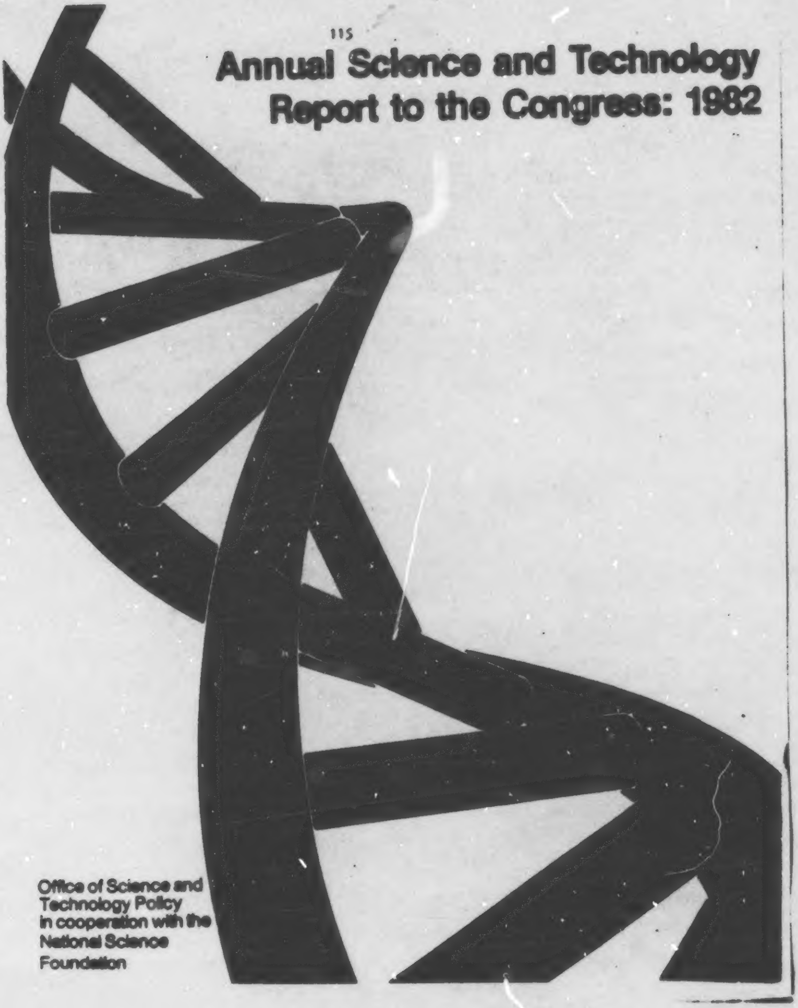
Part 6

THE COMBINED "SCIENCE AND TECHNOLOGY REPORT AND OUTLOOK"

In October 1983, following enactment of the Congressional Reports Elimination Act of 1982, the President submitted the first of the combined "Science and Technology Report and Outlook" reports. Through an oversight, the report cover retained the former title "Annual Science and Technology Report to the Congress, 1982".

The revised legislative charter, corresponding to the Five Year Outlook, states that"the report shall include ... a forecast of emerging issues of national significance resulting from, or identified through, scientific research or in which scientific considerations are of major importance". The combined report is due on January 15th of each odd numbered year.

Chapter II of the report is entitled "Outlook for Selected Fields of Science and Technology" and is reproduced in the following pages.



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Annual Science and Technology Report to the Congress: 1982

Office of Science and
Technology Policy
in cooperation with the
National Science
Foundation

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20500

September 12, 1983

Dear Mr. President:

I am pleased to transmit to you, and through you to the Congress, your Administration's second Annual Science and Technology Report, as required by the National Science and Technology Policy, Organization, and Priorities Act of 1976, as amended.

The Report provides a comprehensive statement of our science and technology policy and priorities. As such it will serve as the basis for continued action in both the Executive Branch and the Congress.

Respectfully,

Jay Keyworth
G. A. Keyworth
Director

The President
The White House
Washington, D.C.

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Chapter II

OUTLOOK FOR SELECTED FIELDS OF SCIENCE AND TECHNOLOGY

This chapter presents a discussion of opportunities for scientific and technological knowledge to make significant contributions to the achievement of Federal program objectives and national goals. The chapter is based on a review of trends and developments in eight selected fields of science and technology that was carried out under the auspices of the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences (NAS).

The eight topics reviewed by NAS and summarized in the first part of this chapter are:

- Surface Science and its Applications
- Turbulence in Fluids
- Lasers
- The Next Generation of Robots
- The Genetic Program of Complex Organisms
- The Molecular and Genetic Technology of Plants
- Cell Receptors for Hormones and Neurotransmitters
- Neurobiology

Based on these eight examples, the chapter concludes with a discussion of possible implications for the organization and conduct of research and development and for the integration of the results of these activities into society. The discussion of these implications is organized under four headings:

- The Emergence of Research-Based Technologies
- The Pace of Technological Innovation
- The Importance of Improving Scientific and Technical Communications
- The Dissolution of Disciplinary Boundaries

SUMMARY OF TRENDS AND DEVELOPMENTS IN SELECTED FIELDS

Surface Science and Its Applications

Surface science is concerned with the first few atomic layers at the surfaces of solids and examines the effects of those layers on the rest of the solid and on other materials. All solids, natural or synthetic, have surfaces, and the character of those surfaces--their structure, their electronic nature, the atoms that they are composed of--can influence the physical and chemical behavior of the entire solid and the interaction of the solid with other atoms and molecules and with external radiation.

Surface science has made great strides during the past decade or two, establishing itself as a basic science capable of experiment and theory that provide detailed understanding at the atomic level. But much remains to be done, both to continue the development of the science itself and to provide a strong base for the important technologies in which surface phenomena figure prominently.

One of the most important tasks facing the surface scientist is to build detailed understanding of chemical reactions at surfaces. The preparation of chemical reactants in specific vibrational and rotational states and the resolution in time of surface processes are new means to this end. Considerable refinement of our techniques for determining the geometrical, electronic, and vibrational structures of both the surface and the species adsorbed on it is in the offing. Improvement in catalytic and energy efficiency can be expected, for example, in such diverse catalytic processes as the production of fertilizers, polymers, refined petroleum, and synthetic fuels.

Another important facet of surface science concerns the role of the geometrical and electronic properties of surfaces in the design, fabrication, and operation of high-speed integrated electronic circuits. The technology will involve further development of multilayer structures having high electron mobility, interfaces or junctions of improved electrical properties, and means of rendering specific surfaces of the new materials passive. Central to an emerging high-speed integrated circuit technology is the fabrication, by molecular beam epitaxy (MBE), of transistors involving well-defined layers of differing atomic composition that are thin enough to permit appreciable spillover of electrons between layers. This new technology will provide logic circuits for higher speed computers, for example. Similarly, optical communication systems will be improved by the extension of MBE techniques to produce semiconducting structures required for lasers and optical detectors in previously inaccessible wavelength ranges.

Our understanding and control of many metallurgical problems of great economic import will be advanced by the use of surface analytical tools. Chemical corrosion, as an example, is a very costly phenomenon occurring on bridges and in nuclear reactors. Detailed knowledge of the process is essential to the design of corrosion-resistant materials or corrosion-preventing coatings. Expensive, empirical, trial-and-error solutions must give way to ideas based on understanding of the relevent phenomena at the atomic level.

The science of surfaces and interfaces is a multidisciplinary endeavor fundamental to many important technologies in addition to those touched on in this brief look at the future. Often, it is difficult to detect what is science and what is technology and which of these in any particular instance is more important to the enrichment of the other.

Turbulence in Fluids

Moving fluids tend toward turbulence, whether they are air, blood, ocean water, the aerosols of clouds, the oil flowing in pipelines, the lithosphere of drifting continents, or galaxies. Turbulence is disordered fluid flow, and understanding what initiates and maintains it is essential to better prediction and control of turbulent events.

The discovery in recent years of mechanical and exactly solvable mathematical systems that lead to chaotic behavior suggests new paths toward understanding turbulence in fluids, whether gases or liquids. Turbulence is the cause of bumpy airplane rides, the rapid mixing of chemicals in industrial processes, the enhanced drag on petroleum flowing in pipelines, and many other phenomena that can be either desirable or undesirable. Scientists and engineers concerned with turbulence are beginning to think more about the mechanism involved, as opposed to its statistical manifestations—more about what actually happens in the fluid, as opposed to statistical approximations of what happens. Such work is yielding a new scientific language—a new way of thinking about turbulence—that promises deeper understanding in the search for universally applicable features of the turbulent process.

Statistical approximations, based on experimental data, are necessary because we have no other way of dealing with turbulence in engineering design and for other practical purposes. After more than 100 years of scientific study, the theory of this immensely complex process has yielded negligibly few quantitative predictions of turbulence. The trend toward mechanistic thinking will not, soon, bring complete or even close to complete understanding of the central problem of fully evolved turbulence. But it offers every hope of leading to the construction of statistical hypotheses that reflect more accurately the underlying mechanisms of the process.

For the near and intermediate term, the goals are to increase our skill at controlling instabilities and to achieve a broad predictive capability for statistical models of turbulence. Such capability would permit both energy savings and improved performance in redesigned pumping systems, compressors, turbines, aircraft, chemical reactors and mixers, and many other products. New understanding of the limits on predictability of the large-scale disorder in weather and in ocean currents can be an early reward of studies of chaos in simpler systems. New awareness of the origins of disorder in natural processes may ultimately be as important a contribution to model building in economics, political science, and ecology as it is to fluid turbulence.

Lasers

Lasers are devices in which atoms, molecules, or ions are made to radiate at frequencies corresponding to separations between their discrete energy levels. The product is light of essentially a single wavelength and phase--coherent light.

Such light is monochromatic, or of one color; highly directional, emerging as a narrow and focused beam; and intense. The wavelength range of laser light has widened considerably in the 25 years since the laser was invented, and many new and novel applications have emerged. In the next several years, both the uses of lasers and their capacities will expand. Lasers are remarkable, not only for what they have done, but for what they now seem on the verge of doing in a range of important applications, extending from lightwave communications to new surgical techniques and medical diagnostic applications to the separation of uranium isotopes.

Existing lasers meet the needs of science and technology over much of the electromagnetic spectrum. New types are needed, however, especially types that produce light of shorter wavelengths and pulse durations than are available today. Tunable lasers should be able to cover the low end of the spectrum to wavelengths as short as 500 angstroms in the far ultraviolet region of the spectrum within the next few years, and pulse durations shorter than 30 trillionths of a second are in prospect.

Existing lasers have become an essential tool for expanding our knowledge of matter, and new types expected soon will provide the basis for an even deeper understanding. High-resolution laser spectroscopy, for example, is helping to confirm the theories of quantum electrodynamics. The same laser methods are contributing steadily to our knowledge of the structure and behavior of solid materials used in electronic and other kinds of devices.

The technology of lightwave communications--the transmission of information by laser light through small optical fibers--is also advancing rapidly. Many systems using first-generation technology are operating, and second-generation technology is well along in development. A prototype system has operated over 101 kilometers of optical fiber at a high data rate and essentially zero error rate.

Lasers are used in industry for many purposes, including drilling, cutting, welding, and surface treatment. In many of these uses, laser processing schemes are peculiarly well adapted to computer-controlled technology. The changes caused by the advent of lasers in industry are likely to accelerate in the near future.

Defense applications of lasers include laser radar and laser target designators. The use of lasers as weapons is complicated by many difficulties, but the field is extremely active. Progress is likely to come in unexpected areas involving specialized applications. Lasers can be used to separate the isotopes of chemical elements, and an isotope-separation process for nuclear fuel and weapons is scheduled for major scale-up. It promises to produce in a single step the enrichment now achieved in the costly, multiple-step, gaseous diffusion process.

Lasers have made considerable progress in medicine, for both diagnosis and surgery, yet the surface has barely been scratched. In addition to many existing applications, the use of a carbon dioxide laser for noninvasive analysis of blood for sugar, urea, and lipids has been demonstrated. The invention of an articulated arm that uses hollow quartz tubes as waveguides is likely to revolutionize carbon dioxide laser surgery in the next 5 years.

The Next Generation of Robots

Robots are computer-controlled devices that reproduce human senses, manipulations, and motions well enough to do useful work. They are now being installed in manufacturing plants, and, in the next several years, major expansion of their uses and capacities will occur.

Although the sensory and manipulative capabilities of industrial robots and their ability to handle unexpected events are still quite limited, robot technology is strengthening and expanding rapidly. Initial commercial success has been achieved through robot mastery of such commercially important operations as spot welding and spray painting. The microelectronics revolution can also be expected to accelerate the development of robotics by supplying many "miracle chips" embodying advanced sensory and control functions.

While robots will only come to perform more industrial operations gradually, their potential near-term uses are extensive. Most favorable for robot application at the moment is the manufacture of items in batches substantial enough for hand manufacture to be undesirable but not large enough to warrant heavy capital outlays on fixed automation. Robotic research is proceeding actively in France, West Germany, Sweden, Japan, and the United States, but Japan leads in the use of robots. Operating industrial robots in 1980 numbered 11,250 in Japan and 4,370 in this country.

Much of the robotic equipment used by industry today is too crude to respond flexibly to changing situations. Much more sophisticated control languages are needed to make industrial robots easy to use and more versatile. Desirable new robot language features include, for example, statements that can cause a manipulator arm to move between specified positions while automatically avoiding certain obstacles or undesirable configurations. In general, we can expect advances in robotic technology to be reflected by the addition of new statements to robot programming languages.

More sophisticated sensory functions, for example, improved image-analysis software, represent another important direction. These sensory capabilities will need to be integrated with manipulator-control software to produce useful industrial closed-loop hand-eye systems.

At present, software for analyzing visual data acquired by robots is not especially reliable and is quite expensive computationally. Improved scene-analysis algorithms are needed if we are to have vision systems that can easily be reprogrammed for a wide range of applications. Deeper understanding of the algorithmic nature of such systems will encourage development of high-performance electronic chips able to handle the required operations very rapidly. As such chips become available, the range of objects that can be inspected economically by robot equipment will expand.

The limited capabilities of present industrial robots indicate that we are far from being able to create general-purpose household robots, which would require sensing and command capabilities far exceeding those needed by industry. Still, it may soon be possible to design robots to perform such relatively simple housekeeping tasks as sweeping large public spaces or mowing lawns. A related possibility is computer-controlled agricultural equipment such as plows and cultivators.

Robots can be expected to continue to take over hazardous, repetitive, and menial tasks and to contribute significantly to the progress of industrial automation under way in this country for the past century. At the same time, robot technology is likely to make certain jobs obsolete while creating others. In the absence of adequate mechanisms for adjusting to this change, severe social tensions may result. The Nation faces the critical task of assessing and alleviating these developing problems, while taking advantage of the ability of robots to enhance productivity and international competitiveness, thereby preserving jobs that might otherwise be lost.

The Genetic Program of Complex Organisms

Until the early 1970s, the direct study of the structure of genes was essentially limited to the DNA of bacteria and viruses, and even that was restricted. The sheer complexity of the DNA of plants and animals, some millions of times larger than that of simple viruses, precluded more than a glance at its organization and a few hints at how it functioned. We knew that the vast genetic system encoded in DNA included the information stored in genes in the form of the genetic code. We also knew that other DNA segments were important in regulating the time and the place in the body where the genes yield up their information in the form of proteins, which account for the structure and metabolic capabilities of cells and organisms. But we were stymied.

Then, with the development of recombinant DNA techniques and, contemporaneously, greatly improved methods for the manipulation of DNA molecules, the picture changed dramatically. As a result, we have learned a great deal about the DNA of plants and animals, including man. We have been surprised to learn how different these complex organisms are from bacteria. For one, the genes in complex organisms are interrupted by other extraneous segments of DNA. Somehow, before the gene can function, the interruptions must be removed and the separate pieces of the gene spliced together. For another, the DNA segments that turn genes on and off at particular times and in particular places in the body are very complex, often composed of several modules that are not even close neighbors of the gene or of one another. And it now seems that genes themselves make up only a portion of the DNA. As much as 20, 50, or even 90 percent of the DNA in different organisms has no known function as yet, and perhaps none at all.

Thirty years ago, genetic experiments with corn hinted that some parts of the DNA might be in flux, with DNA segments capable of moving about from one place to another in these large molecules. Now, we know that this is a general phenomenon, and, in some cases, the events have been studied at the molecular level. Yet, we do not know the biochemical mechanisms involved in the movement, nor do we understand the implications of these mobile DNA segments. The biological process of development of a full plant or a complicated animal from a single cell is now thought of as a precise program in which different genes are turned on and off in orderly fashion at different times and in different kinds of cells. In the case of antibody formation, the developmental program includes precise rearrangements of the DNA sequences themselves.

All of this new knowledge answers a few long-standing questions, but raises an even greater number of new ones. As usual, in science, the most important outcome of the new knowledge is the revelation of unsuspected levels of ignorance. The next 5 years are likely to see progress in understanding splicing, the significance of movable elements, and the signals that turn genes on and off in response to genetically programmed changes or altered cellular environments. These processes are of much more than academic interest. Increasingly, it is becoming apparent that the proper regulation of gene activity is fundamental to healthy organisms, be they crops, important animal food sources, or human beings.

It also appears that rearrangements in DNA may prove to be a common element in the diverse causes of tumors, including chemical carcinogens and viruses. Single genes that cause a normal cell to turn into a tumor cell are being studied. Many of these are a normal part of the DNA of the living host organism. What regulatory changes account for the conversion of a normal gene to a tumor gene? We are coming to understand that many diseases often have heritable components--if not the diseases themselves then a propensity toward them or an inability to defend the body against them.

The past decade has been marked by an extraordinary pace of accomplishment. The techniques are in place and are being improved constantly. Many of the questions that need probing are clear. The next 5 years will provide some of the answers and will surely reveal a new generation of questions. At the same time, the new knowledge is likely to be turned toward imaginative solutions for long-standing problems. New and better chemicals for manufacturing are likely to be produced, new and better drugs and vaccines are likely to be manufactured, new and improved plants may be developed, and diagnosis of diseases will almost certainly be improved. With understanding also may come improved treatments for diseases that have resisted past efforts.

The Molecular and Genetic Technology of Plants

Application of the new techniques of molecular genetics to plant science offers unique possibilities for manipulating plant genes to achieve the long-range objectives of agricultural crop improvement. However, the first requirement is to understand plant gene regulation as it relates to gene structure. Currently, we understand little of the language in which instructions for gene regulation are encoded. A first objective therefore must be the study of several important plant genes to allow us to understand their regulatory signals. With this understanding, we should be in a far stronger position to confront the increased demands for food and fiber resulting from population increases and improvements in living standards.

Some of the demand will have to be met by bringing marginal lands into production. The successful use of such land will require the development of crops that thrive under less than ideal conditions and the adaptation for cultivation of such now underutilized plants as grain amaranth and the winged bean. Given the rising worldwide demand for agricultural products and the fact that modern agriculture is based largely on crops known and cultivated thousands of years ago, the potential of new inquiries into plant genetics and development is enormously significant.

Indeed, the advances in genetic knowledge of the past few years promise ways of breeding new strains of plants that are faster and less expensive than traditional methods. Among these are transferring a gene trait via a soilborne bacterium, *Agrobacterium tumefaciens*, or by using viruses and viroids as vectors to introduce desired genomes into a plant cell. The value of using such genetic carriers is that of transforming higher plants in a planned direction. However, for now, the technique has potential but not practice, due to a still limited understanding of plant genetics. Thus, *Agrobacterium tumefaciens* injects its own DNA into plant cells at wound sites, resulting in cancerous growth and the production of a crown gall. What is not known is the structure of the genetic sequence for tumor induction, including the signals responsible for integrating and expressing that sequence in plant cells. Even without knowledge of these signals, DNA foreign both to the plant cell and to the bacterium has been inserted into plants, along with the tumor-inducing sequence. But such DNA has not been expressed. Further work surely will lead to the ability to use *Agrobacterium*, or other carriers, to insert desirable genes into plants.

The satisfactory culmination of gene transfer requires the ability to regenerate whole plants from single and selected cells or from protoplasts, a process called *totipotency*. In principle, a single plant protoplast can be transformed with foreign DNA and a transformed whole plant then generated. However, as indicated above, deliberate transformation of selected cells is still more potential than practical. And the generation of whole plants from a single cell or protoplast is more of an empirical art than closely reasoned science. Moreover, while some plants, such as potato, alfalfa, and carrot, can be generated from individual cells, others, such as corn, wheat, and soybeans, cannot. Why some plants are experimentally totipotent and others are not eludes present understanding.

However, enough is becoming known of the details of the plant genome that we can begin to understand how viruses and bacteria manipulate the control of gene expression in the plant for their own benefit. And, we can carry out some simple genetic manipulations. This manipulative ability will enable us to learn how the plant controls the expression of its genes in normal growth and development and in response to various injuries.

The refinement of these techniques and the rapidly increasing knowledge of how genes are transferred have created a great sense of excitement and new possibilities among plant biologists. An increased understanding of how plants control gene expression should help us to continue improving crop plants to fit them to our needs more closely than ever before.

Cell Receptors for Hormones and Neurotransmitters

The cells of an animal or a plant must function in an integrated manner for that organism to survive and reproduce. In turn, integration depends upon the ability of the cells to recognize and respond to such chemical signals as hormones and neurotransmitters. That recognition and response relies on special molecules or structures in cells, called receptors. As has been the case for molecular genetics, the last decade has been marked by a rapidly growing understanding of what receptors do and how they work.

Hormones and neurotransmitters coordinate the development and functions of the many specialized tissues of higher animal organisms by acting as chemical messengers that convey information between cells. These messengers bring about their biological effects by first combining with specific receptor molecules in responsive cells.

All known neurotransmitter and hormone receptors are proteins. It is the attachment of the messenger to a particular receptor protein that provides the actual signal to a responsive cell. In some cases, the same hormone may combine with more than one type of receptor and therefore can send cells different messages. If the appropriate receptor cell is lacking or defective, then the physiological responses to a hormone or neurotransmitter will be absent or attenuated.

Receptor studies have increasingly important medical applications. Testing the ability of new chemical substances to bind to specific receptors provides rapid and inexpensive screens for drugs that may potentially mimic or antagonize the actions of various hormones or neurotransmitters in living organisms. This may aid the development of therapeutically valuable drugs. Indeed, receptor studies aided the development of certain antipsychotic drugs and of propranolol for the effective treatment of hypertension.

Since it is a combination of a messenger and its specific receptor that actually cues a cell's behavior, it is conceivable that certain diseases in which the symptoms resemble the result of too litle or too much of a given hormone or neurotransmitter might actually reflect abnormal numbers or functions of a particular receptor, perhaps for genetic or other reasons. Certain rather uncommon forms of diabetes do, in fact, seem to be associated with defective insulin receptors rather than abnormal levels of circulating insulin. Comparably, the neurological disease myasthenia gravis is apparently caused by the blockade of one class of neurotransmitter receptors by antibodies against these receptors manufactured by the patient's own immune system.

Genetically determined defects in receptors for male sex steroid hormones are associated with some rare disorders in which the patients have a normal male complement of sex chromosomes and develop testicles that readily produce testosterone, yet often develop other bodily sex characteristics that are female in appearance. Studies of these diseases, and of comparable disturbances of male sex development in animals, have revolutionized our understanding of the mechanisms by which male or female reproductive organs are formed in the embryo and develop further after birth and at puberty. Tests based on estrogen receptor determinations are of value in selecting alternative treatments for cancer of the human mammary gland. Research on the relationship of receptors to those cancers responsive to several other types of hormones is now under way at many institutions.

Such studies on hormone and neurotransmitter receptors in relation to the cause and treatment of human diseases are still very much in their infancy. There can be no doubt that this important new field will develop tremendously over the coming decade.

Neurobiology

The nerve cells of the brain communicate using chemical and electrical signals to process information through the complex pathways by which we act and think. The search for ways to understand the physical basis of behavior and mind is difficult and only incrementally successful. A spectrum of implications is emerging from research on the brain. These include improved understanding of psychiatric and neurological diseases, the physical basis of learning, and the effects of aging. Through the use of animals in research, we now have a better understanding of the behavioral abnormalities underlying certain aspects of depression and anxiety.

The fundamental scientific challenge for neurobiology is to discover how the biological mechanisms of the brain give rise to complex adaptive behaviors and associated mental processes and how these processes can become disordered in disease states. While the relationship between mind and body remains, in some respects, as mysterious today as it was to the ancient philosophers, there has been an explosive growth in recent years of knowledge about how the brain is organized anatomically and how it functions at the biophysical, biochemical, and physiological levels to produce behavior. This research is producing new insights as to how the brain accomplishes such complex mental acts as learning, remembering, perceiving, and understanding, and how these functions become disturbed in mental illness. Indeed, the realization that mental and behavioral disorders can be linked to abnormalities in brain chemistry and physiology has led researchers to investigate biologically based therapies for a wide range of neurological, psychiatric, communicative, and cognitive disorders.

In the past few years, the principles that guide the development of the embryonic nervous system into the adult brain have been defined more precisely. Substances have been isolated that promote the growth of nerve cells and their interconnections. The transplanting of viable nervous tissue from one brain to another has been realized. It is likely that these discoveries will make it possible to compensate for many types of brain injury as well as for the developmental disorders that result in impaired behavioral functions. At the far end of the lifespan, specific changes in the structure and chemistry of nerve cells have been linked with the profound intellectual decline (dementia) that occurs in some persons as they grow older. While we are a long way from being able to intervene in the normal aging of the nervous system, there are good prospects for developing effective treatments for some forms of dementia over the next few years.

The chemical mechanisms by which nerve cells communicate are now understood in considerable detail, as are the modes of action of many neurotransmitter substances. This knowledge should result in more effective drug therapies for the many neurological and psychiatric disorders associated with abnormalities in specific neurotransmitter systems. The recent discovery of naturally occurring peptide neurotransmitters that exert the same effect on the brain as the opiate drugs (for example, morphine) has substantially altered current conceptions of the neural basis for pain perception. Research on these endorphin neurotransmitters and on the neurophysiology of the pathways that mediate pain is leading to improved methods for alleviating chronic pain associated with injury or disease.

The brain's ability to learn and remember underlies the development of both normal and abnormal behavior, since the majority of our intellectual and emotional characteristics are either learned or modified through life experience. Experiments on simple forms of learning in animals have revealed both the neural pathways involved and the cellular changes that make behavior modification possible. Investigations with human subjects have identified the brain structures critical for the formation of new classes of memories and learned skills. While there are still many gaps in our knowledge, these lines of research are converging toward a comprehensive understanding of how memories are stored and retrieved in the brain, and how they come to be expressed in thought and action.

New methods have been developed toward visualizing the intricate pattern of electrical and metabolic activities that forms a basis for higher cognitive functions. Complex mental acts such as speaking, reading, and paying attention have been associated with characteristic patterns of energy metabolism and neural-electric activity in the brain that can be detected through the intact scalp. The use of these mapping techniques in conjunction with precise behavioral measurements should lead to new conceptual advances in understanding how mental processes are orchestrated in the myriad pathways of the brain.

Implications for Health Care

Trends and developments in the biological sciences, some of which are reviewed in these eight topical summaries, have significant implications for health care in the United States.

The Nation is likely to continue to face escalating costs of treating the chronic diseases that increasingly incapacitate and kill Americans: heart diseases, cancers, arthritis and related disorders, metabolic diseases, and a wide and complex array of psychiatric and neurological diseases. These diseases--successors to such acute illnesses as pneumonia, tuberculosis, infantile diarrhea, syphilis, and typhoid fever as leading killers--have causes that remain unknown and develop in patterns not sharp enough to enable invariably successful intervention. Much of the care applied to them is simply supportive or symptomatic--costly "halfway technologies."

Yet, as several of the topical summaries of this chapter suggest, we now have new windows into many of these disorders. The unraveling of how messages are transmitted from outside to inside the cell, and what happens when that communication system is disrupted, is in turn clarifying the nature of an increasing number of diseases--hormonal illnesses, such as diabetes, and neurological diseases, such as myasthenia gravis.

Receptors, by which cells receive messages, are constructed under genetic direction, as are the molecules that direct the synthesis, storage, and secretions of the neurotransmitters and hormones. Therefore, whatever affects genetic function radiates to receptor structure and function. And this coupling of molecular and receptor biology in turn ties into work on neurological structure, physiology, chemistry, and psychobiology.

New technologies have transformed clinical practices. For example, in gynecological surgery, the carbon dioxide laser has made an enormous impact by changing surgical procedures that once required hospitalization into procedures that can be done during office or outpatient visits, with substantial savings in cost, time, and hospital resources, as well as reduced patient trauma. The same is true for the use of lasers for eye surgery.

There is, at the moment, a virtual explosion of biological knowledge. This may indeed be the era of biology, an era in which the innovative use of instrumentation produced from the contributions of the physical sciences --lasers, large-scale integrated circuits, and computers, for example--is emerging with fundamental insights into the nature of the living cell.

The direct implication is not that chronic diseases will fade. In the next several years, however, there may emerge wholly new approaches to prevention and treatment of these diseases--techniques that are not merely ameliorative but that rest upon penetration of the fundamental causes of the diseases. These techniques will be highly specific, quite complex, and require fundamental understanding for effective application.

IMPLICATIONS FOR THE ORGANIZATION AND CONDUCT OF R&D

Several possible broad implications for the organization and conduct of research and development and for the integration of those activities into society emerge from this topical review of trends and developments in selected science and engineering fields.

The Emergence of Research-Based Technologies

The rapidity of scientific and technological advances links directly to the emergence of new research-based technologies. These are technologies that would not exist without basic research, for which the role of basic research was not to improve but to germinate. Thus, as implied earlier, molecular beam epitaxy could not and did not exist before the perfection of new methods and insights in surface science. The remaining years of the 1980s will see more advanced technologies created by research. There are hints of these in this chapter—totally new approaches to treating major mental illnesses relying on a molecular understanding of how the brain functions; new sensory devices for the handicapped; new tactics for clinical diagnosis and surgery enabled by new lasers; new agricultural insights flowing from a deeper understanding of plant biology; and much more versatile industrial robots.

The implication is that, more than ever, basic science will be vital to technological advance and, in turn, to better productivity and enhanced economic growth and social progress. Although basic science is not inexpensive, it still is the least costly component of technological innovation. And its value in the years ahead will be multiplied as the national economy, both its manufacturing and its service sectors, is suffused by advanced technologies.

The Pace of Technological Innovation

A 1960s study found an average lag of 30 years between basic research and technological application. Today, the lag is much shorter, as evidenced by the accelerating creation and use of new lasers, by the quick exploitation of such new scientific insights as recombinant DNA methods, by the discovery of brain peptides, or by the creation of polymetallic cluster catalysts out of surface studies.

The more rapid pace is also evident in the emergence, within the very recent past, of a new biotechnology industry principally relying on work done in the past 10 years. Similarly, the intense industrial development of very large scale integrated circuits depends on a knitting of fundamental work done almost in parallel, embracing materials and solid-state science, a host of new spectroscopies, and atomic and molecular physics. The character of industrial research and development in many instances has been altered by fundamental work, much of it again within the past 10 years. For example, the pharmaceutical industry has altered its approaches to designing, creating, and testing new drugs, governed by the new understanding provided by receptor biology of how signals enter and change the behavior of cells.

The implication is that we are now in an era of quickening scientific and technological change and that the two intertwine ever more closely. Opportunities are coming so fast, and competition for markets for advanced technologies is becoming so intense, that success will depend directly on the ability to create and then quickly to exploit the new knowledge.

In an era of such rapid transformation, the structures for basic research and technological development must be dynamic and must be constantly freshened by the infusion of new and highly trained scientists and engineers, by adequate instrumentation, and by rapid communication of fundamental knowledge, as discussed below.

The Importance of Improving Scientific and Technical Communications

The intensifying pace of scientific advance and the increasing importance of basic research in gestating new technologies imply that the American research system must exploit to the fullest the new communication modes now becoming available. Possible new approaches to improving the communication of scientific and technical results include electronic networks for the rapid transmittal of "mail" and data, growing numbers and capacities of electronic data bases, and electronic forms of rapid publication.

The importance of these emerging communication modes to the progress of science and technology is intensified by the increasingly interdisciplinary nature of many fields of science and technology. For example, progress in two fields summarized in this chapter--neurobiology and surface science--is generically dependent on scientists and engineers from diverse fields interacting rapidly and extensively. Progress in these fields--and, increasingly, maintenance of excellence in many fields of science and engineering--will depend on sophisticated use of the new communication modes.

It is ironic that although American scientists and engineers pioneer in the development and use of the latest and most sophisticated instrumentation in their experimental work, the instruments they use to exchange information have changed relatively little. With few exceptions, scientists still rely on two major and somewhat traditional forms of information exchange: face-to-face communication (by traveling to national or international meetings) and reading scientific publications (either directly in the office or library, or by requesting the author to send a reprint). Depending upon the scientific locale and the size of the network in which the scientist is involved, the standard sources of information may be supplemented by seminars, letter writing, and the telephone. However, for the most part, the information being exchanged may be anywhere from months to years behind the actual state of the experimental program at the bench or the conceptual progress shared between leading members of a field.

Such continued reliance upon printed statements of progress or upon face-to-face contacts is an unnecessary impediment to the progress of science and technology and to its communication. New methods, based upon advances in electronic communications, could improve substantially the communication of science. Nevertheless, a skeptic might argue that these advances in communication (perhaps viewed as only modest improvements on the telephone) will only contribute to information overload. A major need now is to encourage a comparable advance in "smart" computer terminals through the use of programs that can digest, scan, and analyze the scientific flow of electronically stored information, filter it for each reader's self-defined profile of interests, and then condense the data. The discussion of robots has indicated the importance of the interactions between hardware and software developments for progress in automated machine capabilities. Similar extensive research and development in computer language and artificial intelligence will be required to realize the full scientific and social potential of the new electronic media.

The Dissolution of Disciplinary Boundaries

Finally, traditional disciplinary boundaries are dissolving between the traditional fields of science and between science and technology. As examples of this trend, consider, as described in this chapter, how solid-state physics has merged with materials science and with chemical engineering and computer science to produce new catalysts and microelectronic fabrication methods; how optics, solid-state physics, and cellular biology have merged in the creation of flow cytometry for analyzing cell components; how robotics and neurobiology merge in their analysis of vision. Fundamental studies of how a smoothly flowing fluid becomes a turbulent one devolve into work in mathematics, in physiology, in the dynamics of the atmosphere, and in galactic structure. The search to uncover the structure of cell receptors needs the recombinant DNA techniques of molecular biology. And fundamental work in receptor biology has in turn sparked the discovery of peptide receptors governing neurological events.

The discussion of surface science also makes the point that science and technology increasingly are synergistically coupled. Surface science, in its modern form, is a product of several technologies that provided high-vacuum instrumentation and tools for measuring surface events and structure. In turn, the science has created a potential new technology, molecular beam epitaxy, for building semiconducting layers 100 atoms thick, varying by one or two atoms. Molecular beam epitaxy will surely create a new generation of electronic and electro-optic devices. That advance occurred in the past 15 years, and the rapidity of the progress and application is due to the close coupling of fundamental scientific work with the development and production components of technological innovation.

In fact, instrumentation increasingly knits together science and technology--nuclear magnetic resonance, scanning electron microscopes, a panoply of lasers, new sources of synchrotron radiation, and a vast array of other tools are indispensable to the advances and opportunities recounted in this chapter.

A significant policy implication of these dissolving boundaries concerns the question of which areas of science should have priority support. This becomes more difficult to answer, since advances of knowledge in one field may have a significant effect on understanding phenomena in a quite different field, and the major contributions to instrumentation, technique, and methodology can flow across disciplinary boundaries.

APPENDIX II

THE FIVE-YEAR OUTLOOK ON SCIENCE AND TECHNOLOGY:

Views of Users

H. Russell Cort
Elizabeth C. Cort

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H. Russell Cort
Elizabeth C. Cort
Co-Principal Investigators

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Highlights of Findings

A study of uses of and opinions about the three Five-Year Outlooks (FYOs) in and out of the Congress shows that:

- Most respondents have found the FYOs moderately useful; some considered them extremely useful, some a waste of time and money.
- The greatest need for improvement is in better summarization. Other changes suggested by respondents were in content, organization, presentation, timing or frequency, who prepares the FYO, packaging and dissemination.
- Many people in and out of Congress have used the FYOs for a variety of general and specific purposes.
- Most people skim through them, reading selectively. Relatively few people read an entire FYO in depth.
- The summary volumes or chapters tend to be the more generally useful to the majority of readers interviewed.
- Of 647 people surveyed in the Congress, 179 returned questionnaires and of those, only 65 knew of one or more of the three FYOs.
- In Congress, Committee or Sub-Committee staff members have apparently been the predominant users.
- The predominant uses in Congress have been to identify S&T-related issues for legislative agendas and to prepare hearing background papers.
- The predominant uses of the FYOs in government (other than Congress), in academia, in professional societies, and in industry have been to keep abreast of scientific and technological developments and to identify S&T issues.
- Most users of the Outlooks refer to a variety of other government and non-government source materials as well for the same or related information as that in the Outlooks.
- There has been a commercial market for the first two Outlooks; the Government Printing Office has sold several thousand copies, and there have been larger commercial sales of NAS's contribution to the Outlooks.

I. INTRODUCTION

This is an evaluation of the National Science Foundation's publications, the Five-Year Outlook on Science and Technology (hereafter, FYO), from the point of view of different users or audiences. It provides a depiction of the familiarity with the FYOs of a variety of people in governmental, industrial and academic settings. It describes uses that have been made of the FYOs and ratings of their value for those purposes. The report also gives users' suggestions for improvement of future FYOs, as well as other critical comments.

The main data for this study were collected by two means: (1) structured telephone interviews with samples of possible recipients of the FYOs in the federal government 1/, universities, private businesses, foundations and science and technology societies, libraries, museums, observatories, laboratories, and in private life; and (2) a questionnaire sent to selected members of Congress, their staff, and Senate and House committee staff members. In addition, a number of unstructured background interviews were conducted, directly and by phone, with persons in and out of the government.

The inquiries made covered the following FYOs:

1. The first Five-Year Outlook (hereafter called FYO-1)
    a. The Five-Year Outlook: Problems, Opportunities and Constraints in Science and Technology. May, 1980.
        (1) Volume I. NSF 80-29. This is the FYO per se.
        (2) Volume II. NSF 80-30. Source materials, consisting of a report from the National Academy of Sciences, statements by selected government agencies, and papers on selected topics commissioned by the National Science Foundation.

1/ Not including OSTP and OMB.

2. The second Five-Year Outlook (hereafter called FYO-2)

   a. *The Five-Year Outlook on Science and Technology: 1981*. January, 1982. NSF 81-40. This is the FYO *per se*.

      (1) Source Materials, Volume 1. NSF 81-41. This contains a report from the National Research Council.

      (2) Source Materials, Volume 2. NSF 81-42 [2]. This contains a report from the American Association for the Advancement of Science, a report from the Social Science Research Council, and federal agency perspectives.

3. The third Five-Year Outlook (hereafter called FYO-3)

   a. *Outlook for Science and Technology: The Next Five Years. Volume III*. November, 1982. This is a report by the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences, National Academy of Engineering, Institute of Medicine for the National Science Foundation,

   or

   b. *Frontiers in Science and Technology: A Selected Outlook*. A report by the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences, National Academy of Engineering, Institute of Medicine. New York/San Francisco: W.H. Freeman and Co., 1983. This book, published commercially, was substantively the same as the *Outlook for Science and Technology: The Next Five Years. Volume III* (3a, above). [3]

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[2] The present study was not required to include this document, but it was nevertheless included in the questionnaire sent to the Congress.

[3] NAS had previously published its first two contributions to the FYOs through W.H. Freeman as well.

The report of the Committee on Science, Engineering, and Public Policy (hereafter COSEPUP) that we have called FYO-3 was in fact published with no substantive change by the NSF in September, 1983 as The Five-Year Outlook on Science and Technology: 1982 (NSF 83). There were thus three different publications (same content) of FYO-3. With few exceptions, it was the COSEPUP preprint of FYO-3 or its commercial version (3a and b above) with which people in this study were familiar. 4/

The Five-Year Outlook (FYO) was a report required of the Office of Science and Technology Policy (OSTP) by Section 206 of the National Science and Technology Policy, Organization and Priorities Act of 1976 (PL 94-282). 5/ The report was to be an annual one to aid the Director of OSTP to "... identify and describe situations and conditions which warrant special attention within the next five years, involving (1) current and emerging problems of national significance that are identified through scientific research, or in which scientific or technical considerations are of major significance; and (2) opportunities for, and constraints on, the use of new and existing scientific and technological capabilities which can make a significant contribution to the resolution of problems identified under paragraph (1) of this subsection or to the achievement of Federal program objectives or national goals, including those set forth in section 101(b) of this Act." 6/

Responsibility for the FYO was transferred to the National Science Foundation by President Carter's Reorganization Plan

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4/ COSEPUP, in the late spring of 1983, also published, through W.H. Freeman, Frontiers in Science and Technology: Summary. This booklet contains the summary and overview chapter of the larger volume, plus the table of contents of the eight areas covered in FYO-3.

In October, 1983, The Annual Science and Technology Report to the Congress: 1982 was published by OSTP. Chapter II of that report, entitled "Outlook for Selected Fields of Science and Technology," was a compilation of summary excerpts from FYO-3. In that respect, there have been four versions of the third Outlook.

5/ An excellent history of the legislation may be found in Wells, William G., Jr., Science Advice and the Presidency: 1933-1976. Doctoral Dissertation, The George Washington University, December, 1977.

6/ PL 94-282, Section 206(a).

§1, and implemented by Executive Order 12039. 7/ The NSF has subsequently sought the assistance of NAS and others in preparing source materials which form the major bases for the Five-Year Outlooks per se. 8/ Agreement was reached with Congress that the FYO should be done only every other year. The Congressional Reports Elimination Act of 1982 (PL 97-375) required the combining of the FYO into a single report with the Annual Science and Technology Report, and shifted responsibility for the report back to OSTP (see footnote 4 above).

The FYOs have been an impressive and evolving undertaking. Few countries attempt anything comparable. The NSF and others involved have largely had to create their own models and to improve them on the basis of experience. 9/ The changes from FYO-1 to FYO-2 to FYO-3 have been marked and, especially in FYO-3, dramatic.

The fate of future FYOs is now at a crossroad. We hope the results of the present study will help in decisions about future directions.

7/ For a discussion of OSTP's early position on and involvement in the FYO, see The Office of Science and Technology Policy: Adaptation to A President's Operating Style May Conflict with Congressionally Mandated Assignments. Report by the Comptroller General of the United States. PAD 80-79, September 3, 1980.

8/ As noted, the COSEPUP report to the NSF did in effect become FYO-3.

9/ "Preparation of the first Outlook has provided us with many lessons about science and technology forecasting and prediction, and about the production and integration of large quantities of technical material which an Outlook requires. We are using those lessons in preparing the second Outlook." Statement of Dr. Harvey Averch, NSF, before the Subcommittee on Science, Research and Technology of the Committee on Science and Technology. U.S. House of Representatives, June 13, 1980.

II. METHODOLOGY

What started as the intention to mail questionnaires to a scientifically designed sample of recipients of FYOs, based on mailing lists to be provided by the NSF, ended as a mailing to Congress and telephone interviews with others. The main steps in the present study were as follows.

A. Pre-design study.

In order to determine how best to frame questions and item choices about uses and opinions about the FYOs in a manner that would make sense to a wide variety of respondents in many different settings and positions, it was planned to do a preliminary semi-structured telephone survey of small, randomly selected samples of addressees from the NSF mailing list. It was also planned to interview a limited number of knowledgeable and involved people in the federal government, including Congress, to obtain background information about the FYOs and about issues and interests in them.

The NSF Division of Information Systems provided computer-generated lists of six main categories of persons, ordered by Zip Code within category, which NSF believed had constituted one of its main distributions of FYO 1 and 2. [1] In addition, since some NSF directorates and divisions had sent copies to their Advisory Committee members, lists of persons who were members as of 30 June 1982 were provided. NSF also provided assorted other lists, including foreign embassies in the U.S. and U.S. embassies abroad believed to have received FYOs and some personal requestors of copies. [2] We also obtained the distribution list of SSRC for FYO-2.

A random sample of about five people, on the average, in each of 14 categories [3] was called. Brief, open-response interviews were conducted. The results of those 70 interviews convinced us that about 40% of the listed addressees

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[1] The categories were: Governor's Science Advisors; Presidents -- State Academies of Science; Science Resource Study Publications -- R&D Funds Full Report; Scientific and Technical Societies; Research Administrators; and Former Members -- National Science Board.

[2] COSEPUP subsequently provided some distribution lists for FYO-3.

[3] Including the six main computer-generated categories of mailing lists.

(on the average) were invalid for purposes of this study. [4] It was further concluded that, owing to variations in settings and in understandings, a mail survey would yield very marginal, if not worthless, results.

On the basis of this part of the pre-design study, it was decided, in concurrence with the NSF, to change to a telephone interview approach. The pre-design study provided much information needed for designing the telephone interview forms (see Appendix C, Instruments).

It was also decided, based on consultation with the NSF and two Congressional committee staff members, to proceed with a mail questionnaire to the Congress. During the pre-design study, interviews were held with a member of a Senate and a House Committee staff. On the basis of those interviews, and with the help of consultants, the Congressional questionnaire was designed.

Additional information contributing to the design of the Congress form and the telephone interview form came from interviews conducted with selected individuals (19 in all) in a number of agencies, including NSF, NAS, OSTP, GAO and CRS, as well as a small number of knowledgeable people not in the government.

B. Telephone Interviews

For most categories of lists (other than federal agency lists) provided by the NSF and COSEPUP, a one-third systematic sampling with a random start was used in each category to identify persons to be called (see interview form in Appendix C, Instruments). If a person selected could not be reached after a maximum of four attempts, the next person on the list was selected. If the person could be reached, but referred to another person in the organization as more knowledgeable, the latter was called as an alternate. If the person called did not know of any FYO, or did not feel he or she could give opinions about them, the interview was terminated, but was counted nevertheless as a contact. All persons who proceeded with the full interview were offered confidentiality at the beginning and again at the end, if they wished it. [5]

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[4] They were invalid for various reasons, the main one being that the person contacted had not received or did not know of any FYO. Other reasons included: the person on the list had died; had left the organization and could not be located; the phone operator had no telephone listing for the name or organization.

For federal agencies or organizations, with the exception of NSF, sampling was used if there was a number of people on the lists who were in the same organizations. [6] In addition to the lists, we also selected as interviewees persons in federal agencies whose position titles suggested a technical or administrative responsibility for science, technology, research or innovation. Sixteen departments, agencies, administrations, commissions, institutes and centers were included, not including NSF. [7] In the NSF, effort was made to try to interview all technical directorate and division heads, plus a few other persons on NSF internal distribution lists. [8]

The first call in each of six categories was used as a form of pilot test. A few wording changes were made on the basis of those results. All calls were made from mid-September through the end of November, 1983.

C. Congressional Questionnaire

The Congressional form (see Appendix C, Instruments) was distributed on October 25, 1983, to all Members of Congress, and office and committee staff members who were on distribution lists provided by NSF and COSEPUP. It was also distributed to all Senators and Representatives and their legislative assistants, and to all Majority and Minority Committee or Sub-Committee Staff Directors who were not on the NSF or COSEPUP lists, if those persons were on committees or sub-committees believed to have an active interest in science or technology. See Appendix B for a list of Committees and Subcommittees included.

A stamped return envelope was provided. Each questionnaire contained an attached sign-off slip so we could keep track of what groups responses came from and do a follow-up if need be. Confidentiality was assured to all respondents.

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[5] Thirty-one percent did so choose. There were six inadvertent exceptions, which were subsequently coded arbitrarily as selecting confidentiality.

[6] OTA and CRS (from the COSEPUP lists) are cases in point.

[7] OSTP and OMB were not included.

[8] Sixty-three percent of such intended interviews were completed.

A follow-up mailing was done on November 7, 1983 to 52 Senate and House Committee staff members from whom we had not yet received responses.

The total Congressional mailing was to 647 persons. Three returns received after December 22, 1983 were not processed.

D. Data Processing

All forms were edited and provided additional coding as needed. They were key-punched and verified by the Computer Science Center of the University of Maryland, where computer analyses were also run, using SPSS.

E. Analyses

Most analyses were descriptive. They involved examining frequency and percentage distributions. In cases in which it was of interest to test hypotheses about the significance of differences between groups, Chi-square tests were used. 9/

9/ Since, for questions such as uses of the FYOs, the tests involved multiple comparisons from the same respondents, a Bonferroni level of significance was used to provide a set-wise significance level of .05. Thus, $p = .05/n$, where n is the number of tests to be made. For example, to compare government and non-government respondents' distributions on nine use items, $p = .05/n = .05/9 = .006$ for each test.

III. RESULTS

A. To Whom Do the Results Pertain?

1. Congress

A total of 647 questionnaires was distributed, and 179 responses were obtained. There was a total completed distribution of 644, and therefore a response rate of 27.8%. Of those potential 644 respondents, 65 (or 10.1%) indicated some familiarity with, or at least awareness of, one or more of the three FYOs. Table 1 shows the results by category of respondent. 1/ Note that Table 1 includes two respondents who knew of one or more FYOs but whose category membership could not be classified from the information returned. 2/

It may be seen in Table 1 that Senate and House Committee staff members responded at a higher rate and were proportionately more likely to know of the FYOs than members of the other categories. 3/ It is the 65 respondents who knew of one or more FYOs on which all subsequent analyses of the Congressional questionnaires are based.

2. Interviews Based on NSF/NAS Mailing Lists

Four hundred and ninety-two (492) individuals were contacted by phone. Of these, 11 were librarians who were given a special interview (see Appendix C, Instruments). Their responses will be treated separately. Thus, the main pool of data came from 481 possible interviewees.

1/ See Appendix B for list of committees included in the questionnaire distribution.

2/ Strictly speaking, they could also be classified as non-respondents for tabulation purposes.

3/ We cannot, of course, draw any conclusions about the 72.2% of the total survey that did not respond.

Table 1. Congressional Questionnaire Distribution and Response, by Category.

Category	No. Sent	No. Returned	% of Category Total	No. & % of Respondents Aware of 1 or More FYO 6/	
				N	%
Senators	80	18 4/	22.5%	4	22.2%
Representatives	194	21 5/	10.8%	5	23.8%
Senators' Staff	84	26	31.0%	7	26.9%
Representatives' Staff	202	65	32.2%	18	27.7%
Senate Committee Staff	39	20	51.3%	11	55.0%
House Committee Staff 1/	45	27	60.0%	18	66.7%
Committee Unclassifiable 2/	0	1	--	1	100.0%
Generally Unclassifiable 3/	0	1	--	1	100.0%
Totals	644	179		65	

1/ Includes Executive Directors of the Congressional Clearinghouse on the Future and the Congressional Caucus for Science and Technology.

2/ Could not tell whether respondent was staff member of a Senate or House Committee or Sub-Committee.

3/ Could not determine whether respondent was a staff member of a Committee or of a Member's office.

4/ Includes five Senators who said their policy was not to answer questionnaires.

5/ Includes one Representative with policy of not answering questionnaires.

6/ These are percentages of the respondents in each category, not of the total distribution.

While over 50 categories of possible interviewees were coded (by, for example, treating each NSF Advisory Committee as a separate category),[4] for purposes of analysis the data were grouped into 12 categories. Table 2 shows the sample characteristics by category; it also shows the general prevalence in each category sample of at least probable awareness of one or more of the FYOs.

Persons contacted in the study included corporation presidents and vice-presidents; university presidents, vice-presidents, provosts, deans, research and/or grant coordinators and administrators, professors; science attaches in embassies; federal agency under-secretaries, directorate heads, division and department heads, science, research and technology advisors; retired scientists, professors and presidents emeritus, and others. They were physical, biological, behavioral and social scientists; physical and mental health scientists, engineers, computer scientists, information scientists, and biotechnology specialists; educators, administrators, managers and generalists; and policy specialists and planners, to name some of the main fields of professional endeavor. Some (about 39%) were interested mainly in science or technology *per se*; some (about 27%) were interested mainly in science and technology policy; some (about 25%) were interested both in substantive and policy matters; and some had other main interests. They were located in 46 states (343 persons) [5], the District of Columbia (125 persons); overseas U.S. embassies (13 persons). [6] Table 3 shows the distribution of interviewees in several major types of settings, and the prevalence of general awareness of one or more FYOs in each.

3. Librarians

Of the 11 librarians given special interviews, 9 were on the main computer-generated NSF mailing lists. They had copies of different FYO volumes, as shown in Table 4. The majority had the first two FYOs. The librarians interviewed came largely as the result of the overall sampling from the main mailing lists. In some cases, they came about as the

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[4] This was done in part because initial sample identification was done by category rather than by the total of all the different lists.

[5] The 10 predominant states were: New York (40); California (39); Massachusetts (35); Texas (19); Michigan (18); Pennsylvania (15); Maryland (12); Connecticut and Ohio (each 10); and Colorado (9).

[6] Overseas embassies and organizations contacted were in: Australia, Austria, Bulgaria, England, France, Hungary, India, Israel, Japan, Romania, Russia, and Sweden.

Table 2. Categories and Numbers of Persons Interviewed, and Prevalence of Awareness of One or More FYO.

Category	Category Total	# & % of Persons Contacted		# & % Aware of One or More FYO		# & % Unaware of FYOs	
		N	% 1/	N	% 2/	N	% 2/
1. Federal Government 3/	123	71	57.7	42	59.2	29	40.8
2. NSF Officials	41	26	63.4	26	100.0	0	0.0
3. Former NSB Members	60	19	31.7	18	94.7	1	5.3
4. Current NSB Members	23	6	26.1	6	100.0	0	0.0
5. S & T Societies	166	51	30.7	24	47.1	27	52.9
6. Research Administrators	283	95	33.6	55	57.9	40	42.1
7. SRS/R&D Funds Report	182	48	24.6	18	37.5	30	62.5
8. Governors' Science Advisors	28	6	21.4	3	50.0	3	50.0
9. Pres.-State Academy of Science	32	5	15.6	0	0.0	5	100.0
10. NSF Advisory Committees	576	125	21.7	68	54.4	57	45.6
11. General Lists, U.S. Requestors	45	14	31.1	11	78.6	3	21.4
12. Embassies (Mostly U.S. Overseas)	53	15	28.3	11	73.3	4	26.7
Totals	1,612	481 4/	29.8	282	58.6	199	41.4

1/ These are percentages of the total numbers of persons in each category. Category 1 consists of 7 sub-categories, which were in turn based either on lists provided by NSF or NAS, or on individuals selected in a number of Federal Agencies because of their positions. Thus, there is no category total comparable to those of categories 3-12. Category 2 was based on a sample from the NSF Executive and Mangement Council lists (excluding members of the Office of the Director), plus 20 of 23 Directorate and Division Heads (or their replacements) that were not included in the Council samples. Category 10 is based on 25% samples, on the average, from each of 16 NSF Advisory Committee lists. Category 10 totals exclude the 16 persons called in the pre-design study. Categories 3 and 5-9 contain the computer-generated mailing lists provided by NSF. The totals for each of those categories exclude all non-U.S. addressees and all persons contacted in the pre-design study (of which there were 38 in all).

2/ These are percentages of the number of people contacted in each category.

3/ Does not include OSTP or OMB.

4/ Does not include the 11 librarians given special interviews. If they are included, the total percentage contacted is 492/1612 = 30.5%.

Table 3. Types of Settings and Numbers of People Interviewed, and Prevalence of Awareness of One or More FYO.

Types of Settings	Number Contacted	# & % Aware of One or More FYO		# & % Unaware of FYOs	
		N	% 1/	N	% 1/
1. Societies, Associations, Foundations, Institutes	65	33	50.8	32	49.2
2. Colleges, Universities	216	117	54.2	99	45.8
3. Local, State, Federal Agencies	125	85	68.0	40	32.0
4. Companies, Corporations	42	24	57.1	18	42.9
5. Other	33	23	69.7	10	30.3
Total	481	282		199	

1/ These are percentages of persons contacted in each type of setting, not including librarians.

Table 4. Number and Percentage of Librarians Holding FYOs (11 Libraries).

FYO Volume	Have		Do Not Have	
	N	%	N	%
1. FYO-1 (Vol. I)	9	81.8	2	18.2
2. FYO-1 (Vol. II)	7	63.6	4	36.4
3. FYO-2	8	72.7	3	27.3
4. FYO-2 (Vol. 1)	6	54.5	5	45.5
5. FYO-2 (Vol. 2)	5	45.5	6	54.5
6. FYO-3 (NAS Vol. III)	2	18.2	9	81.8
7. Frontiers (Freeman)	3	27.3	8	72.7

result of a person contacted who referred the caller to the organization's library. [7]

4. Groups Not Included

There are large numbers of persons who have or have seen one or more FYOs who were not included for consideration in the present study. For example, the Government Printing Office's sales lists were not included for consideration in this study owing to limitations of time and resources. As of August 10, 1983, the GPO had sold 1,402 copies of FYO-1 (Vol. I), and 1,149 copies of FYO-1 (Vol. II). [8] It had sold 805 of its 1,000 copies of FYO-2 (the summary report only), and 357 of its 1,000 complete sets of FYO-2 (that is, the summary and the two source materials volumes). In addition, we know that many copies of each FYO were distributed informally by people in different agencies or organizations. There is no way of determining those distributions in any systematic sense, any more than we could establish who had obtained the FYOs through libraries or through taking courses in universities. The reader should consult Appendix A for a listing of the number of copies of each FYO printed.

The data presented here thus pertain generally to a number of groups, including members and staff members of Congress, that the NSF and we felt were important and could identify with mailing or distribution lists or position titles. The lists that we used constitute a small fraction of total printings of the FYOs.

B. Familiarity with FYOs

1. Congress

The Congressional questionnaire did not specifically ask about degree of awareness or familiarity. Forty-five percent (45%) of the 65 respondents aware of any FYOs indicated that they were aware of all three; 25% indicated awareness of only one of the three. The second FYO (FYO-2) was the most widely known of the three (80% of the 65 knowledgeable respondents knew of it). FYO-1 and FYO-3 were somewhat less widely known (66% and 68%, respectively, knew of them). Committee staff members were the most likely of the groups responding to know of any or all of the FYOs (66% of 29 staff members checked awareness of all three).

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[7] In some organizations, incoming documents are routed directly to the library; in others they are sent to the library after having been received by the addressee.

[8] Information provided by GPO, August 10, 1983.

3. Telephone Interviewees

Of the 282 persons contacted who said they were aware of one or more FYOs, 61 (or 22%) indicated that they knew of all three. The remaining 78% knew of one or more but not all three. Of the 191 who were willing to express opinions,[9] 44 (or 23%) were aware of all three FYOs. Sixty-four (64, or 34%) were aware of only one of the three FYOs, and the remaining 83 (43%) were aware of some combination of two of the three FYOs. Awareness of FYO-1 was stated by 142 (74%), of FYO-2, by 154 (81%) and of FYO-3, by 70 (37%) of the interviewees.

The 191 interviewees who proceeded with the full interview were asked to indicate roughly the extent to which they had read the FYOs. Most people answered in terms of one of three categories. Percentages choosing each category for each FYO are shown in Table 5. The majority of respondents considered that they had skimmed (or perhaps browsed through or speedread) the reports, or, at most, read all or parts once.[10]

Our general impression was that the majority of people interviewed skim through the FYOs selectively, noting details in topics that interest them and perhaps returning to obtain specific information as the need arises. This impression was supported by the fact that the majority of respondents (about 60% for each FYO) found the summary volumes (the FYOs, *per se*, or the summary chapter in FYO-3) more useful for their purposes than the source material volumes. That proportion varied somewhat according to the particular FYO and the category of respondents. For some respondents, the source materials or chapters were more useful for their purposes, and some, of course, stated that whether the FYO *per se* or the source materials were more useful depended on his or her particular purposes.

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[9] Or more precisely, who were willing at least to start a complete interview.

[10] The categories may be viewed as indications of degree of familiarity with the FYOs, but they are gross at best for supporting inferences about depth of knowledge of content. The question was asked before questions about usage. Since the utilization questions often stimulated memory, one should view the extent of familiarity indications as conservative.

Table 5. Extent to Which FYOs were Read.

	Extent of Reading in Percentages of Respondents 1/				
FYO	Have Read All or Parts More Than Once	Have Read All or Parts Once	Have Seen Report, May Have Skimmed Through All or Parts	Can't Say for Sure	N 2/
FYO-1	6.4%	30.5%	58.2%	5.0%	141
FYO-2	5.3%	30.9%	61.2%	2.6%	152
FYO-3	0.0	40.9%	51.5%	7.6%	66

1/ The percentages are for each FYO individually.

2/ Many of the same individuals are represented in each row, because most knew of more than one FYO.

C. Uses of the FYOs

The FYOs can serve two main purposes: general education and the generation of awareness and ideas; and provision of information relevant to more specific purposes or needs. 11/ We sought to obtain indications of use and value bearing on both areas of impact.

1. Congress

Table 6 shows the list of uses or purposes contained on the Congress questionnaire, and the percentages of respondents who indicated using a particular FYO for each purpose. 12/ The prevalence of reported utilization for a given purpose varied somewhat with the FYO, but was generally similar across the three FYOs. For example, some of the more commonly reported uses of the three FYOs were:

- preparing hearing background papers (Item 1 in Table 6);
- identifying S&T-related issues for legislative agendas (Item 2);
- assessing national needs (Item 3); and,
- writing speeches, articles (Item 4).

The use-rate was higher, proportionately, on the average, for FYO-3 than for the other two FYOs.

It should be noted that because an FYO was used relatively less often in connection with a particular task does not necessarily mean it was irrelevant to that task. It could also mean that some of the respondents did not happen to do that task.

In this report the data from different groups or categories of respondents have been combined to give an overall depiction of trends or tendencies. Comment is made _passim_ on differences or similarities among groups. The data collected were analyzed by group or category before they were combined, as in Table 6. The reader will find in Table A of Appendix D a breakdown of utilization rates for each of three main Congressional groups: Members of Congress, Legislative Assistants and other office staff, and Senate and House Committee staff.

Most respondents who indicated using an FYO for various tasks also rated the usefulness of the FYO on a scale of 1-10, where 10 means extremely useful. Table 7 shows

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11/ These two functions seem to cover the various objectives explicit in the legislation and implicit, at least, in its development.

12/ For each FYO, the percentages were based on the number of respondents indicating that they knew of that FYO. Those numbers were 45 (FYO-1 and FYO-3), and 54 (FYO-2).

Table 6. Uses of FYOs in the Congress:
Number and Percentage of Respondents Indicating Each Use 1/

	FYO-1		FYO-2		FYO-3	
	%	N	%	N	%	N
1. Preparing hearing background papers	51.1	23	38.9	21	57.8	26
2. Identifying S&T related issues for legislative agendas	48.9	22	44.4	24	60.0	27
3. Assessing national needs	48.9	22	35.2	19	55.6	25
4. Writing speeches, articles	44.4	20	37.0	20	55.6	25
5. Identifying S&T related issues for oversight agendas	37.8	17	33.3	18	44.4	20
6. Preparing floor remarks	35.6	16	27.8	15	46.7	21
7. Evaluating budget requests	31.1	14	29.6	16	44.4	20
8. Determining oversight priorities	31.1	14	27.8	15	37.8	17
9. Doing foresight or futures research activities	31.1	14	25.9	14	42.2	19
10. Determining legislative priorities	26.7	12	20.4	11	33.3	15
11. Writing legislative reports	24.4	11	24.1	13	26.7	12
12. Dealing with lobbyists, interest groups	24.4	11	22.2	12	35.6	16
13. Responding to inquiries from constituents	24.4	11	25.9	14	40.0	18
14. Proposing legislation	20.0	9	13.0	7	26.7	12
15. Identifying potential witnesses	20.0	9	16.7	9	26.7	12
16. Writing oversight reports	20.0	9	20.4	1[illegible]	28.9	13
17. Drafting legislation or amendments	17.8	8	16.7	9	[illegible]	10
18. Other (Please list or describe on back of sheet)	0.0	0	0.0	0	0.0	0
Overall Average per Item 2/	31.8%		27.0%		40.3%	
Median Percentage 2/	32.0%		26.4%		40.1%	

1/ All percentages are based on the number of respondents who indicated awareness of a particular FYO. For FYO-1, N=45; for FYO-2, N=54; and for FYO-3, N=45.

2/ Does not include Item 18, Other.

Table 7. Mean Ratings of Value of FYOs for Different Purposes in the Congress. 1/

	FYO-1		FYO-2		FYO-3	
	Mean	N	Mean	N	Mean	N
1. Identifying S&T related issues for legislative agendas	6.72	18	6.68	19	7.05	21
2. Doing foresight or futures research activities	6.69	13	7.00	14	6.56	18
3. Assessing national needs	6.53	19	6.77	17	6.68	22
4. Determining legislative priorities	6.30	10	5.70	10	5.57	14
5. Writing speeches, articles	6.24	17	6.71	17	6.50	22
6. Preparing floor remarks	6.20	15	6.64	14	6.63	19
7. Identifying S&T related issues for oversight agendas	6.07	14	6.13	15	6.06	16
8. Determining oversight priorities	5.91	11	5.75	12	5.86	14
9. Preparing hearing background papers	5.53	17	5.19	16	5.90	20
10. Identifying potential witnesses	5.50	8	5.75	8	5.00	11
11. Dealing with lobbyists, interest groups	5.36	11	5.58	12	6.00	15
12. Writing oversight reports	5.33	9	5.00	10	4.82	11
13. Writing legislative reports	5.30	10	4.64	11	4.55	11
14. Responding to inquiries from constituents	5.27	11	5.15	13	5.47	15
15. Drafting legislation or amendments	5.14	7	4.43	7	4.89	9
16. Proposing legislation	5.13	8	5.00	7	4.75	12
17. Evaluating budget requests	4.31	13	5.00	15	4.68	19
18. Other (Please list or describe on back of sheet)	0.0	0	0.0	0	0.0	0
Unweighted Average 2/	5.74		5.71		5.70	
Median 2/	5.53		5.70		5.88	

1/ Based on a scale of 1-10, 10 being extremely useful.

2/ Does not include Item 18, Other.

the average ratings of the three FYOs for each listed purpose. [13] Unweighted average ratings for the three FYOs were 5.74 (FYO-1), 5.71 (FYO-2), and 5.70 (FYO-3). The three medians of the average ratings were, respectively, 5.53, 5.70 and 5.88. For FYOs 1 and 3, "identifying S&T-related issues for legislative agendas" received the highest average usefulness rating. For FYO-2, the highest average usefulness rating was for "doing foresight and futures research activities." All three FYOs were rated relatively low in usefulness for "evaluating budget requests."

Most respondents who knew of more than one FYO and rated their usefulness for a particular purpose did not differentiate between the FYOs in their ratings. While Table 7 shows average ratings for each purpose, the ratings by individual respondents were quite varied, ranging from as low as 1 to as high as 10 for some items.

For each FYO, there was a significant, positive relationship between the proportionate frequency of use of the FYO for a particular purpose, and the average rating of its usefulness for that purpose. Higher ratings of usefulness for a given purpose tended, for each FYO, to go along with higher prevalence of use. The product-moment correlation coefficients for these two variables for FYO 1, 2 and 3, respectively, were: .57, .55, and .79 (all were statistically significant at the .05 level or beyond).

While overall mean usefulness ratings of the three FYOs were about the same, the medians of the mean ratings increased from FYO-1 to FYO-3. The variation of mean ratings for the 17 purposes for FYO-3 was not significantly greater than for the other two. The shape of the distribution of averge ratings was somewhat different, however. The effect was no change in unweighted overall mean, but a higher median average rating. There also were some variations in the mean ratings of the usefulness of FYO 1, 2 and 3 for particular purposes, as can be seen in Table 7.

Committee staff members tended to be the predominant users of the FYOs, and of those, proportionately more so in House than Senate Committees. House Committee staff members tended to rate usefulness slightly higher for the same uses and FYOs than did Senate Committee staff members.

Relatively few Congressional respondents made any narrative comments about use of the FYOs. A number of people who knew of one or more FYOs simply noted, "Don't use" or "Not used." Other comments on usage were:

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[13] Most respondents who did not use an FYO for some purpose left the item blank. A very few occasionally rated an item 1, but otherwise left blanks. Some people filled in all spaces for all FYOs with a number. For example, one respondent noted that he or she was unfamiliar with FYO-1 and systematically put 1 in each item space for it. In those cases, we arbitrarily counted 1 as blank (meaning "not used" for that purpose).

- "Report is used for 'staff education'" -- a Senate Committee staff member.

- One House Committee staff member noted that the FYO was intended to be written and used by OSTP for program and budget planning purposes and that delegation of it to any other body defeats the purpose of Section 206 of PL 94-282. This person also said that the FYOs " ... are potentially useful for several of the items listed under [Question] II. My responses refer to my own specific use. Because the reports cover broad areas and Congressional activities are usually focused on a narrow area, the reports will always be only a minor consideration in any specific activity. The reports are useful as background information, to the extent they get read, but it is hard to associate background knowledge with specific activities."

- "As you can see the main use has been writing speeches and statements for my members. When issues come up, I generally contact appropriate information sources directly. There certainly is no lack of issues for the legislative agenda, so I do not find myself in the position of looking for issues. The reports have been used for assessing priorities." -- a House Committee staff member.

- "I'm afraid that the documents as presently presented are not useful to me in my work, basically because they do not drive funding decisions." -- a Senate Committee staff member.

- "The reports are useful as background and are suggestive of specific areas for future Congressional interest, but Congress is essentially a reactive body. The reports play little, if any, role in setting the legislative agenda." -- a Senate Committee staff member.

- "These are largely just catalogues now, not very insightful, largely irrelevant to framing issues before Congress. In the Defense area, they are particularly weak." -- a Senator's staff member.

2. Persons Interviewed by Phone [14]

a. Uses

Most interviewees were read a checklist of uses similar to that used in the Congress form, but shorter and tailored to a broader audience. The relative prevalance of different uses of the three FYOs is shown in Table 8. 15/ The majority of interviewees have used the FYOs for keeping informed about science and technology developments. A sizeable proportion of people have also used FYOs for identifying developments in science or technology. These two uses seem to fall under the educational and "horizon-scanning" function of the FYOs. Some more specific applications included use in preparing professional books, papers or speeches (predominantly talks or speeches), determining policies or strategies, and preparing development plans or programs. The first two FYOs were used proportionately somewhat more often 16/ for the purposes listed than FYO-3.

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[14] Does not include the 11 librarians given special interviews.

No large, statistically significant differences in the prevalence of particular uses were found among different categories of interviewees, or between government and nongovernment groups. Rates of respondents in different categories reporting different uses tended to rise and fall with the overall percentages shown in Table 8. People in government agencies were somewhat more likely than people in private business to use the FYOs for preparing budgets, for example, and the latter were less likely to use them for teaching than were people in academia or in S&T societies or institutes or foundations. Generally, however, rates of different uses were quite similar among different categories of respondents. The reader interested in the breakdown of utilization rates for each purpose and FYO, by category of interviewee, should consult Tables B and C in Appendix D.

Most people (66%), when asked if they had used the FYOs for purposes other than those in the checklist, said they could not think of other uses. Interviewees often said the checklist covered the possibilities well. Those who did mention other uses often gave purposes similar to those on the checklist. Some people made it clear that they used them for trend or issue scanning; for reference material; for multidisciplinary information; or for funding or economic information. Some people used them in conjunction with talks or discussions, or to give to others (e.g., to foreign dignitaries and scientists). Science attaches abroad are particularly likely to do the latter. One person in industry used them as an information base for coordinating research and development between divisions in the company. Another person noted, sardonically, that they were used as a cure for insomnia (not everyone thought well of them). A recipient of the FYOs (not included in the data in Table 8) noted that he scrupulously made a point of never looking at them since "... those predictions are always wrong."

People in organizations were asked if there were others in the organization (department, etc.) who used the FYOs. Over half said "yes", less than 20% said "no", and the

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15/ Percentages for a given item and FYO are based on the number of people indicating awareness of the FYO. See legend in Table 8.

16/ That is, by larger relative percentages of interviewees.

Table 8. **Uses of FYOs at large:**
Number and Percentage of Interviewees Indicating Each Use 1/

Use	FYO-1		FYO-2		FYO-3	
	%	N	%	N	%	N
1. Generally keeping informed on S&T developments	86.6	123	88.3	136	65.7	46
2. Identifying S or T issues, opportunities or problems	50.7	72	55.2	85	41.4	29
3. Preparing professional books, papers or speeches	46.5	66	45.5	70	35.7	25
4. Determining policies or strategies	46.5	66	48.1	74	34.3	24
5. Preparing or recommending organization's development plans or programs	40.1	57	40.3	62	31.4	22
6. Preparing testimony for Congress or state or local legislature	19.7	28	20.1	31	10.0	7
7. Teaching	19.0	27	18.2	28	11.4	8
8. Preparing budgets	17.6	25	22.1	34	14.3	10
9. Proposing or preparing legislation	8.5	12	7.8	12	5.7	4
Overall Average per Item	37.2%		38.4%		27.8%	
Median Percentage	38.0%		38.0%		31.8%	

1/ The percentages for each item and FYO are based on the number of interviewees indicating awareness of the particular FYO. For FYO-1, N=142; for FYO-2, N=154; for FYO-3, N=70.

remainder were not sure. Those who answered affirmatively were asked if they could estimate about how many. Many could not. For those who could, the median estimate was about three other people. In some large organizations and in some teaching situations, estimates were 20 or more.

The FYOs have been disseminated in many ways that go beyond the mailing lists used in the present study. The practice of handing them on, or of obtaining other copies, occurred in all categories of interviewees.

b. Ratings of Relative Value

Interviewees on the phone were not asked to rate the usefulness of the FYOs for each purpose they identified, unlike the procedure used with the Congressional form. They were asked to rate the usefulness of the FYOs on a scale of 1 to 10 for their purposes, compared to other reports of their kind. Some people felt they could not make such an evaluation. Others could only evaluate the FYOs in general, not particular ones.[17] The ratings that were made by individuals, as in the case of the Congress, ranged from 1-10. The average rating for each FYO is shown in Table 9.

Table 9. Average Ratings of Comparative Usefulness by Interviewees.

	FYO-1	FYO-2	FYO-3	FYOs Generally
Mean	6.38	6.72	7.12	6.23
N	73	85	25	39

These averages run about a half point to a point and a half higher than the unweighted average ratings for all items made by Congressional respondents (see Table 7). Some interviewees felt they could not make such an evaluative judgment because they believed that the FYOs were unique.

Near the end of the interview, people were asked for their overall opinion (on a four-point scale of "extremely useful" to "useless" that was read to them) of the general utility of the FYOs for their purposes. The results are shown in Table 10.[18] The majority of people responding chose "moderately useful" to characterize the FYOs; roughly comparable proportions chose "extremely useful" or "not very

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[17] Also, of course, people were not asked to rate FYOs with which they were unfamiliar.

[18] Again, the same reasons for non-response as above apply.

Table 10. Percentages of Ratings of Overall Usefulness by Interviewees.

	1 Extremely Useful	2 Moderately Useful	3 Not Very Useful	4 Useless	5 No Opinion	N
FYO-1	12.2%	72.2%	13.9%	0.0%	1.7%	115
FYO-2	15.1	72.2	9.5	0.0	3.2	126
FYO-3	19.5	63.4	14.6	0.0	2.4	41
FYOs Generally	11.1	61.1	11.1	11.1	5.6	18

useful"; and two people decided upon "useless." 19/ These distributions seem, with the center of gravity on moderately useful, sensibly compatible with the comparative ratings on the ten-point scale.

c. Other Sources of Information Considered More Useful

Interviewees were asked if there were other reports or source materials they found more useful than the FYOs for the purposes they had identified. A majority of respondents gave a response, very often referring to professional or technical journals in their field of interest. A wide range of other sources was also mentioned, including: various NSF publications, including the Annual Science and Technology Report, Science Indicators, and Mosaic; Office of Technology Assessment reports and Congressional Research Service reports; Congressional reports, Science 83; Scientific American; American Scientist; Science Digest; The Wall Street Journal, and others. Some people mentioned personal contacts and networking. Some individuals stated, as previously noted, that there was nothing comparable to FYOs. Others felt that the FYOs were simply compendia of information already available elsewhere.

When asked about their uses and ratings of the FYOs, many respondents made evaluative comments (either positive or negative, or sometimes both). These will be discussed in the context of suggestions for improving the FYOs.

d. Libraries

Most of the librarians interviewed had no way of determining how often the FYOs were used. Three of the 11 said they were used frequently. A few librarians could identify the main users. For most, however, it was not possible to do so, or to estimate how many different people used them. It would take more time and effort than was possible in the present study to assess systematically the extent of library usage of the FYOs.

D. Suggestions for Improvement

1. Congress

A checklist of possible improvements in future FYOs was provided on the Congressional questionnaire, as well

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19/ One respondent made a statement to the effect that although he had no use for the FYOs, since he had looked at them he could not logically categorize them as useless. Others commented that the FYOs were simply not particularly relevant to their situation or needs.

as space for making other suggestions or comments. Table 11 shows the number and percentage of respondents who checked each suggestion. The prevalence of endorsements of different suggestions did not differ significantly (statistically) between staff committee members on the one hand and Members of Congress and their staff assistants on the other. The Congressional respondents clearly wanted to see better summarization, suggestions for legislative actions, and indications of changes since the last FYO. There was also considerable interest in prioritization of needs, problems and opportunities. The relative order of interest in different possible improvements or changes seems to be a response in part to the needs of busy people on the Hill for easily absorbed material and focused conclusions. We will see, however, that a similar order of interest prevailed among many interviewees in and out of government.

As before, there were only a few additional comments made by Congressional respondents. They were:

- "Do it less often, make the books less catalogues and tie the papers to issues on the Congressional agenda or which should be on the agenda. Contract out to NAS/NAE only. NSF's reports are not useful (lowest common denominator). AAAS papers generally not of high caliber." -- a Senator's staff member.

- "The report is too much a consensus document. It ought to reflect to some degree the disagreements in science that could impact public policy." -- a Senate Committee staff member.

- "The report to Congress was intended principally to focus on national problems to which science and technology can contribute and only secondarily on the status of scientific disciplines. The Five-Year Outlook focuses almost exclusively on disciplines in the most recent [FYO-3] issue." -- a House Committee staff member.

- "The Five-Year Outlook is useful now to support positions already established. To be more useful for long-term needs changes such as [better delineation of anticipated social, economic and political impacts or problems] and [assignment of priorities to needs, problems, and opportunities] are necessary. Prioritization is especially important even if not totally scientific or with full consensus." -- a House Committee staff member.

Table 11. Suggestions for Improvement: Congressional Respondents.

Suggestion	Percentage Endorsing 1/	Number
1. Short, 5-10 page summary	75.4	47
2. Recommendations for legislative actions needed	67.7	44
3. Clearer statement of changes since the last FYO	49.2	32
4. Assignment of priorities to needs, problems, and opportunities	41.5	27
5. Better delineation of anticipated social, economic and political impacts or problems	38.5	25
6. Improved presentation format (e.g., more charts, tables, graphics)	21.5	14
7. Less scientific and technical material	16.9	11
8. More specific delineation of relationships between areas, problems, and opportunities	15.4	10
9. Better dissemination to relevant audiences	15.4	10
10. Other (Please describe.):	1.5	1 2/

1/ Based on the 65 respondents who were aware of one or more FYO.

2/ The suggestion was: "Keep it short."

- "The FYO should be sent to all Congressional offices. Suggest wider dissemination to Congressional utaff involved in S&T matters. Unless it gets to them, the report is of little use. The report would also be more useful if condensed." -- a House Committee staff member.

2. Interviewees

a. Responses to Suggested Kinds of Improvements

Responses of interviewees to a list of possible improvements in future FYOs are given in Table 12. There were no statistically significant differences in response distributions between respondents in the government and all others. Government respondents tended to be more conservative than others about endorsing "more emphasis on speculative or controversial forecasts." They tended to be less conservative about endorsing more emphasis on anticipated social and economic costs and problems, and on more attention to international implications. Generally, however, the proportionate distributions of responses in both groups were very similar. So also were the distributions of responses of the few people who knew only of FYO-3, compared to those of all other respondents.

Congressional and non-Congressional groups tended to endorse similar suggestions for improvement in similar orders of prevalence or importance. Seven of the items on the interview list and the Congressional form were very similar. The rank order correlation between the two groups of respondents for those items was high ($r_s = .79$) 20/.

A few comments on some of the data in Table 12 are appropriate. With respect to Item 4 (more emphasis on anticipated social and economic costs and problems), a number of people said it would be desirable but noted that no one knows how to do it. Some felt that continued efforts in this area would be valuable. With respect to Item 8 (more emphasis on controversial or speculative forecasts), many of the people who thought that would be helpful did so only with the provision that it be done carefully, building responsibly on past experience and data ("on reality as we have known it"). A few senior scientists felt there is need for a forum for self-evaluation of the scientific and technological enterprises and that the FYOs might be an appropriate one. Item 5 (more attention to policy and legislative implications and actions) revealed sharp differences of opinion among

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20/ $p < .05$.

Table 12. Would Any of the Following Be a Significant Improvement in Future FYOs? Interviewees' Responses.

	Percentages of Responses [1]				
	Definitely	Perhaps	No	No Opinion	N
1. Five to ten page summary of most significant trends, issues and possible problems or impacts. .	70.5%	16.5%	9.1%	4.0%	176
2. Clearer statements of changes since the last *Five-Year Outlook*.	60.9	17.8	10.3	10.9	174
3. More attention to international implications . . .	45.1	21.7	22.3	10.9	175
4. More emphasis on social and economic costs and problems anticipated from future science or technology developments	40.6	24.6	28.0	6.9	175
5. More attention to policy and legislative implications or actions	40.5	24.9	24.9	9.8	173
6. More delineation of relationships between areas, problems and developments	38.2	25.9	19.4	16.5	170
7. More graphs, tables, charts	32.2	19.9	20.5	27.5	171
8. More emphasis on speculative or controversial forecasts.	22.3	26.3	36.6	14.9	175
9. Less scientific or technical material	8.6	10.9	68.4	12.1	174

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[1] Percentages may not add exactly to 100.0 percent due to rounding.

respondents (scientists and non-scientists alike). Some believed that reports on the state and directions of science and technology from the scientific and technological communities should be clear, authoritative, reliable statements of just that. They should not attempt to speculate on political matters (" ... to add the irrational to the rational ..." in the words of one respondent). Others believed that it was important, perhaps inescapable, that legislative concerns and political directions be addressed. Some people, especially overseas science attaches, believed that OSTP should indicate what it sees as directions from the President's perspective.

Finally, it should be noted that some people, perhaps more immediately and extensively familiar with the FYOs, rejected some of the suggestions listed on the grounds that the FYOs (especially FYO-2) already emphasized them sufficiently (e.g., Item 3 in Table 12, international implications).

b. Other Comments and Suggestions

About one-third of the people interviewed offered their own comments and suggestions about the FYOs, especially FYO-1 and FYO-2. Evaluative commentary ranged from very enthusiastic and laudatory (the FYOs are first-rate publications, should keep going just as they are, keep up the excellent work) to very critical (the FYOs are useless, a waste of time and money). Some people saw an improvement in content and organization from FYO-1 to FYO-2. Some people thought the FYOs were articulate and well presented; others thought they were too wordy, and poorly organized and presented for ease of use.

Substantive suggestions for improvement tended to group into a limited number of categories. Predominant among those were: content, organization and presentation, timeliness, who prepares them, and dissemination. 21/ A number of people felt there needs to be more attention to engineering, to applications and industrial concerns, and to the "soft" sciences (the latter not just from social scientists). A number of people raised questions about the process and criteria for selecting topics for inclusion. They wondered who chose issues or topics to be included in each FYO, and what the bases for selection or exclusion were.

21/ In considering all responses, it is important to bear in mind that respondents were relying on impromptu memory, not on careful study and analysis of the FYOs preparatory to an interview. Some people offered to do just such preparation.

Suggestions for changes in organization ranged from comments on summarization or highlighting to style to packaging. Some believed the sheer compendiousness of the FYOs was inhibiting (some people tended to think of the FYO proper and the source materials as a unit). 22/ A few people suggested that the FYOs could perhaps be repackaged in more modularized form so that reports or bulletins on different topics or issues could be easily updated and disseminated as needed rather than having to rely on a single complete production in all or even selected areas.

The latter suggestion overlaps with a number of comments about timeliness. Those who seemed to use the FYOs for keeping abreast of scientific and technological developments for whatever reasons were apt to note that there were more current souces of information available. Those who seemed interested in broader futures or trend analysis tended to think that FYOs were not needed so frequently.

Finally, a number of people raised questions about dissemination. There was at least concern about the bases of dissemination and about whether the FYOs were getting to people who could use them. Some felt better advertising was needed, as well as wide distribution of boiled down summaries or descriptive brochures or pamphlets (such as, perhaps, COSEPUP's Frontiers in Science and Technology: Summary, 1983). 23/

Some people believed that it is inappropriate to evaluate documents such as the FYOs by what people say about how they use them. The FYOs should be viewed as contributing to an on-going awareness (a continuous raising of awareness) about scientific and technological issues, developments and opportunities. From the structured and open-ended responses of people in many settings, it is evident that they do serve that purpose. Typically, suggestions offered were intended to make the FYOs more readily accessible and easier to assimilate. Some, however, who acknowledged what they called the encyclopedic nature of FYO-1 and FYO-2, felt they were unique and valuable contributions -- excellent reference works. 24/

22/ One overseas science attache noted, rightly or wrongly, that the British and the French were usually better at condensing complex material.

23/ Not included in the present study.

24/ One person put it this way: "They seem to stay on my bookshelf longer than many other reports."

IV. DISCUSSION

A. Usefulness of FYOs

There is no question that a variety of people, in the Congress, federal agencies, [1] industry, academic settings, and professional societies said they have found one or more of the FYOs useful for a variety of purposes. It is also clear that there is a substantial range of opinion about the usefulness of any one of the FYOs for any of the purposes about which respondents were asked or about which they talked. On the average, opinions about the FYOs were that they have been moderately useful. [2]

The preface to the second Five-Year Outlook discusses a broad function of the FYOs as one of three reports (the *Annual Science and Technology Report* and *Science Indicators* are the others) that aim "... to provide a set of tools useful for policy planning and assessment." [3] The preface also notes that: "The *Five-Year Outlook* is not meant to, nor does it represent the official policies of the U.S. Government. Rather, it serves as an inter-agency discussion document and a focus for raising problems that might merit policy consideration in the coming years." [4] The data of this study suggest that the FYOs have been used by people in and out of government in connection with: policy and program planning, budget preparation, and preparation of legislation or testimony before Congress or other legislative bodies. Slightly greater percentages of people at large have used the first and second FYOs for these purposes, perhaps because they have been available longer than the third FYO, or because they had been more widely distributed in the groups we sampled. In the groups of Congressional respondents in this study, the third FYO has received somewhat more use, proportionately, in a number of legislative tasks than the first two FYOs.

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[1] All data and discussions explicitly exlude consideration of OSTP and OMB.

[2] Averages are, of course, simply that. For any given purpose, each FYO has been extremely useful to a few, and of little or no use to a few, in most groups.

[3] *The Five-Year Outlook on Science and Technology: 1981.* National Science Foundation, January 26, 1982, p. vii.

[4] *Ibid*, p. vii.

The data of this study do not show whether the FYOs have served as an inter-agency discussion document (only one government interviewee mentioned anything suggesting that directly, although some people, not in government, mentioned using FYOs for discussion purposes of one kind or another). The data do show that a number of people in and out of government have used the FYOs to identify science or technology issues, opportunities or problems. They also show that in the Congress there are those who have used them to identify science and technology-related issues for legislative and oversight agendas, for futures research activities, and for assessing national needs.

Just how valuable are the FYOs for such purposes? There is, of course, no simple measure (or possibly any satisfactory measure) to answer that question. Our data do not suggest, nor is it our subjective impression from the interviews we had, that there would be a measurable impact on the kinds and quality of analyses, orientations, or decisions if the FYOs, as they have been conceptualized and written, were to cease. [5] People in need would find other sources, perhaps at a higher cost to themselves in time and effort. The FYOs are one of a variety of sources available to (and described by) people to whom we talked. For some organizations, the FYOs pull together data, analyses and information that the organization cannot afford to do itself. For some people, they serve to confirm, reinforce or lend credence to already held ideas and understandings. For some people, they are superfluous, repetitive and not very timely.

The FYOs have been an experiment. They have been evolving. Our data do not show sharp differentiations in most people's appraisals of the three FYOs. Some people we talked to who were sufficiently familiar with all three to offer a comparative statement thought the evolution was in a positive direction.

Do the FYOs aid in horizon-scanning? Do they aid in long-range planning? The answer the data of the present study suggests is, in both cases, yes, in an unsystematic, scattered and idiosyncratic way. In an affirmative vein, there are those who are interested in both functions, and if they come across the FYOs, they take them (more specifically, various aspects or parts of their contents) into account in varying degrees of detail. The broadest implication of the data is that the typical user could be characterized as an FYO-scanner. Few read them from cover to cover. Few study them in depth. Many scan them, dipping in selectively in more depth according to their needs and interests.

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[5] We know of no purpose for which only FYOs are used.

Answers (even tentative answers) to questions of utility depend, at least in part, on answers to prior questions about audiences or users, about mechanisms for use, and about purposes. Some hints of those come from consideration of some of the suggestions for improvement that were made.

B. Suggestions for Improvement

Respondents from the Congress, and persons interviewed in and out of the government, were in surprising agreement about steps that might be taken to improve the FYOs for their purposes. Of all possible changes, better summarization, or highlighting, should be a high priority. Since the FYOs are likely to be scanned, better depiction of highlights or main points is needed. The first two FYOs do provide executive summaries and the source material chapters each have summaries. The third FYO has a six-page overview of the subsequent eight topical chapters, which in turn each have an outlook summary. Notwithstanding, there still appears to be a need for attention to ways of presenting salient points in a more arresting and accessible manner.

The third (or latest) FYO [6] is a marked departure from the first two in organization, scope and content. Congressional respondents as a group tended to indicate more utilization of it than of FYO-1 and FYO-2, on the average. Few respondents who knew of all three FYOs and rated their usefulness for particular purposes, however, differentiated between them in their ratings. Nevertheless, FYO-3 would seem to be a major step in the direction of meeting at least some needs for summarization. COSEPUP's recent summary booklet of what essentially became the third FYO is yet a further step in the direction many people thought was needed.

Part of the problem in retrieving and using information from past FYOs may be uncertainty in some readers' minds about the framework within which the different subjects and ideas of the FYOs occur. A number of interviewees wondered how and why topics were selected (or excluded). Cumulative indexing would help dispel some of the confusion.

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[6] The reader is reminded that the third official FYO was known to respondents in this study mainly through the COSEPUP and W.H. Freeman distributions.

Part of the problem may be institutional tradition and policy. Some people wondered if NSF was the right agency to do such reports. While there was and is widespread and very genuine respect for NSF publications, some people believed that by the time the NSF has produced a report such as the FYO, the contents have been thoroughly smoothed and homogenized, or rendered bland and unprovocative. It will be recalled that government interviewees tended to be less likely than others to believe that more emphasis on speculative or controversial forecasts might improve the FYOs. 7/ That disinclination may contribute to a report organization and presentation that works against attention-commanding summarization or forceful presentation.

Part of the problem may be how FYOs are conceptualized and how their use by different audiences is imagined or understood by their writers. There is a variety of ways of organizing, presenting, packaging and disseminating five-year outlook-types of information, depending on what one is trying to accomplish, with what audience or audiences, and under what assumptions of need and utilization. For example, if one assumes that a function of the FYO is to contribute to immediate or short-term program and budget planning, that is one matter. That aim will help set the timing, scope, organization and content of FYOs. If one assumes an alerting function, or perhaps a long-range policy and planning function, that is a somewhat different matter. If one assumes a general educational function, that is another matter. If one assumes that a function is to help institutionalize long-range planning in the government, that is yet another matter. Again, if one assumes a variety of audiences with a variety of responsibilities and mechanisms for monitoring, processing and using information (a multi-purpose audience), one might consider a series of FYO-type packages of different depths, formats and timing. 8/

7/ There was no great difference between NSF and non-NSF government interviewees on this issue. On the other hand, there was a substantial difference between NSF personnel and NSF Advisory Committee personnel. The latter, predominantly scientists in university settings, were twice as likely to consider this possibility affirmatively under the proper conditions.

8/ A number of interviewees made suggestions along these lines.

Content decisions for FYOs also follow from decisions about audiences, purposes and mechanisms for monitoring, processing and using information. The checklist data in Tables 11 and 12 indicate some general areas of possible content change. While many interviewees noted that it was impossible to anticipate social and economic costs and problems associated with future science and technology developments, they also thought it would be useful to try to do so. A number of interviewees were concerned about the broader social milieu and implications of science and technology. It is possible that some alternative plausible scenarios, rather than precise [illegible] methodologically exact predictions, would be useful. [illegible] but related vein, a number of interviewees thought [illegible] FYOs have shown an overemphasis on the "hard" as [illegible] from the "soft" sciences (again, this came not just from social scientists).

Some persons interviewed made comments about the detail and specificity of the FYO content. Some linked this aspect to thoughts about who would use the FYOs. One person noted, for example, that while the FYOs might be suitable for technical program managers, they were far too detailed for the needs of high-level policy makers. An experienced policy analyst declared flatly that they were useless for policy-making purposes.

Relatively few people in or out of the Congress thought there should be less scientific material in the FYOs. That would seem to contradict the need for more summarizing and condensing. There need be no contradiction, however, if one imagines a cascaded set of packages, perhaps along the lines COSEPUP has taken with its Frontiers in Science and Techology: A Selected Outlook, and its Summary booklet.

Finally, a word on dissemination. Judging by results of the Congressional questionnaire, the FYOs have not been systematically reaching people in the Congress (especially Committee staff members) who might find them of interest, even in their (FYOs') past forms. Yet Committee staff members have probably been the main users. It is possible that not only a more systematic distribution approach, but also briefings or seminars would aid in constructive dissemination and information utilization among Members of Congress and staffers alike.

Science and technology societies, it appears, would benefit from having a press release or flyer accompany a copy of the FYO so they can more easily notify their memberships of the FYO's availability. One person suggested dissemination, at least of a flyer, through NTIS.

We may note that in the NSF and NAS distribution lists used in this study, there were, for example, no banks, no investment firms or institutions. There were consultants on the lists who questioned distribution bases. Our general impression of the NSF and NAS distribution lists we have used is that they have been somewhat idiosyncratic and, in some areas, alarmingly out of date. We received a number of complaints about the latter, especially from people who had tried repeatedly and unsuccessfully to get name or address changes into the computerized mailing system.

As with other areas of suggestions and comments, decisions about methods of dissemination depend strongly on decisions about the intended audience (or audiences) and its expressed needs, and how it interacts with the report producers.

V. CONCLUSIONS AND RECOMMENDATIONS

The findings of the present study support three main conclusions:

1. The *Five-Year Outlooks* have served a number of different purposes and have been used by a wide variety of people in government, industry, academia, and scientific and technological societies. Except for the Congress, the purposes served by the *Outlooks* in each of these settings have been similar. In Congress, the latest *Outlook* appears to have received the most use, proportionately.

2. While general opinions about the *Five-Year Outlooks* ranged from highly positive to very negative, the *Outlooks* were regarded, on the average, as moderately useful. From the first to the last *Outlook*, there was some indication outside of the Congress of an increase in the usefulness of them.

3. A number of changes were recommended by respondents from the Congress and elsewhere. Better summarization was the most frequent recommendation. There were also important changes suggested concerning content, organization, packaging, timing or frequency of publication, who prepares the reports, and dissemination.

In sum, the results of the present study suggest that the *Five-Year Outlooks*, as they have been conceptualized and implemented, have served a number of broad and specific purposes moderately well. It is appropriate now to reassess the aims of the *Outlook*. That reassessment should include consideration of the intended audience, the contents, the timing, the packaging, and systems for dissemination. If a decision is made to continue *Outlook* efforts, changes in each of those areas are much needed, as are much more substantive and frequent communications between the producers and the primary intended audience, the Congress.

APPENDICES

APPENDIX A

The following publication figures of the number of copies of the three FYOs printed were provided by the NSF and NAS.

A. **NSF**

1. FYO-1: 3,000 copies [1]
2. FYO-2: 5,000 copies [2]
3. FYO-3: 3,500 copies

B. **NAS**

1. FYO-3: 1,100 copies [3]
2. FYO-3 (Freeman): 6,000 copies [4]
3. FYO-3 (Summary): 1,500 copies [5]

---

[1] About 1,500 went to the Government Printing Office for sale.

[2] 1,000 to the GPO.

[3] This was the *Outlook for Science and Technology: The Next Five Years, Volume III*, November, 1982.

[4] This was *Frontiers in Science and Technology: A Selected Outlook*, published by W.H. Freeman & Co., April, 1983.

[5] This was *Frontiers in Science and Technology: Summary*, published for COSEPUP by W.H. Freeman and Co., and distributed by COSEPUP to Congress in June, 1983.

APPENDIX B

Questionnaire Distributions and Returns, by Congressional Committees and Sub-Committees

SENATE	Sent	Returned 1/	Knew of FYOs
Agriculture Nutrition & Forestry	x	x	
Agricultural Research & Gen. Legislation	x		
Appropriations	x	x	x
Defense	x		
Energy & Water Development	x	x	x
HUD - Independent Agencies	x		
Labor, HHS, Education	x	x	x
Armed Services	x	x	
Budget	x	x	x
Commerce, Science & Transportation			
Science, Technology & Space	x	x	x
Democratic Policy Committee	x	x	x
Energy & Natural Resources	x	x	
Energy Research & Development	x		
Environment & Public Works	x	x	
Environmental Pollution	x		
Toxic Substances & Environmental Oversight	x		
Governmental Affairs			
Energy, Nuclear Proliferation & Governmental Processes	x	x	x
Judiciary			
Constitution	x	x	x
Labor & Human Resources			
Education, Arts & Humanities	x		
Small Business			
Innovation & Technology	x	x	x

1/ In some cases, only Committee affiliation could be determined.

HOUSE OF REPRESENTATIVES

	Sent	Returned[1]	Knew of FYOs
Agriculture	x	x	
Department Operations, Research & Foreign Agriculture	x	x	x
Appropriations	x	x	x
Defense	x		
Energy & Water Development	x		
HUD-Independent Agencies	x	x	x
Armed Services			
Research & Development	x	x	
Budget	x	x	x
Energy & Commerce	x	x	x
Health & the Environment	x		
Foreign Affairs			
International Security & Scientific Affairs	x	x	x
Interior & Insular Affairs	x	x	
Energy & the Environment	x		
Merchant Marine & Fisheries			
Oceanography	x	x	
Science & Technology	x	x	x
Energy Development & Applications	x	x	x
Energy Research & Production	x	x	x
Investigations & Oversight	x	x	x
Natural Resources, Agriculture Research & Environment	x	x	x
Science, Research & Technology	x	x	x
Space Science & Applications	x	x	x
Transportation, Aviation & Materials	x	x	
Congressional Clearinghouse on the Future	x		
Congressional Caucus for Science & Technology	x	x	x

---

[1] In some cases, only Committee affiliation could be determined.

APPENDIX C

INSTRUMENTS

Congressional Form

- Cover Letters
- Sign-off Slip
- Form

Telephone Interview Forms

- Main Form
- Librarian Supplement

Five-Year Outlook Evaluation Project
P.O. Box 7417
Silver Spring, MD 20907
(301) 565-07[illegible]
October 21, 1983

Dear [Senator's or Representative's name]:

The National Science Foundation has contracted with the undersigned to do an evaluation of its Five-Year Outlooks on Science and Technology from the user's point of view. As you know, the Five-Year Outlook reports are required by P.L. 94-282, The Science and Technology Policy, Organization, and Priorities Act of 1976, as amended by the Congressional Reports Elimination Act of 1982 (P.L. 97-375).

A central goal of this evaluation is to obtain feedback about the views and opinions of people in the Congress. To that end, we have designed a short, simple form that we respectfully ask you to complete and return to us. A stamped, return envelope is enclosed.

All returns will be kept confidential. Data will be reported statistically, or in terms of comments attributable only to groups, not to individuals. However, in order to classify returned forms correctly, and to keep our survey records accurate, we ask that you please complete the attached slip and return it with the questionnaire. We will remove it from the questionnaire when we receive it.

Even if you are unable to answer any of the questions, please sign the slip attached to the form and return both in order that we can have an accurate and complete survey record.

Let me thank you in advance for your prompt consideration in providing this much desired and important feedback.

Sincerely yours,

H. Russell Cort, Ph.D.
Principal Investigator

HRC:sw

Enclosures

Five-Year Outlook Evaluation Project
P.O. Box 7417
Silver Spring, MD 20907
(301) 565-0785
October 21, 1983

Dear [Staff member's name]:

The National Science Foundation has contracted with the undersigned to do an evaluation of its Five-Year Outlooks on Science and Technology from the user's point of view. As you know, the Five-Year Outlook reports are required by P.L. 94-282, The Science and Technology Policy, Organization, and Priorities Act of 1976, as amended by the Congressional Reports Elimination Act of 1982 (P.L. 97-375).

A central goal of this evaluation is to obtain feedback about the views and opinions of people in the Congress. To that end, we have designed a short, simple form that we respectfully ask you to complete and return to us. A stamped, return envelope is enclosed.

We will keep all returns confidential. Data will be reported statistically, or in terms of comments attributable only to groups, not to individuals. However, in order to classify returned forms correctly, and to keep our survey records accurate, we ask that you please complete the attached slip and return it with the questionnaire. We will remove it from the questionnaire when we receive it.

If there is someone else on your staff in a better position to respond, please pass this package on to him or her.

Even if you are unable to answer any of the questions, please sign the slip attached to the form and return both in order that we can have an accurate and complete survey recor

Let me thank you in advance for your prompt consideratio in providing this much desired and important feedback.

Sincerely yours,

H. Russell Cort, Ph.D.
Principal Investigator

Enclosures

Sign-Off Slip

Please complete and return this slip with the questionnaire. It will be removed from the questionnaire when we receive it.

Thank you,

H. Russell Cort, Ph.D.

1. Name (Please print):

2. Title (Please check or describe):

   __ Senator
   __ Congressman, Congresswoman
   __ Staff Member (Please say what Office or Committee or sub-committee):

   ____

   ____

Form Approved
OMB No. 3145-0061
Expiration Date: 6/30/84

FIVE-YEAR OUTLOOK (FYO) EVALUATION FORM: CONGRESS

I. PLEASE CHECK ANY OF THE FOLLOWING YOU ARE AT ALL FAMILIAR WITH OR AWARE OF:

A. The Five-Year Outlook: Problems, Opportunities and Constraints in Science and Technology. May, 1980. (1st FYO):

1. Volume I (Summary) ___(1)
2. Volume II (NAS, Govt Agency Reports; Papers) ___(2)

B. The Five-Year Outlook on Science and Technology: 1981. Jan., 1982 (2nd FYO):

1. The Five-Year Outlook (Summary report) ___(1)
2. Source Materials: Vol.1 (National Research Council, NAS, Report) ___(2)
3. Source Materials: Vol.2 (AAAS, SSRC, Govt Agency Reports) ___(3)

C. Outlook for Science and Technology: The Next Five Years, Vol. III, Nov., 1982 (3rd FYO). (National Academy of Sciences Report for the National Science Foundation). (Also published by NAS as: Frontiers in Science and Technology: A Selected Outlook. W.H. Freeman, 1983.) ___(1)

II. HAVE YOU HAD OCCASION TO USE ANY OF THE ABOVE REPORTS (FYO's) FOR ANY OF THE FOLLOWING PURPOSES? IF SO, WOULD YOU PLEASE RATE THEIR USEFULNESS FOR THOSE PURPOSES ON A SCALE OF 1-10 (10 MEANS EXTREMELY USEFUL).

	1st FYO	2nd FYO	3rd FYO
1. Proposing legislation	___	___	___
2. Drafting legislation or amendments	___	___	___
3. Preparing hearing background papers	___	___	___
4. Identifying potential witnesses	___	___	___
5. Evaluating budget requests	___	___	___
6. Identifying S&T related issues for legislative agendas	___	___	___
7. Identifying S&T related issues for oversight agendas	___	___	___
8. Determining legislative priorities	___	___	___
9. Determining oversight priorities	___	___	___
10. Doing foresight or futures research activities	___	___	___
11. Preparing floor remarks	___	___	___
12. Writing speeches, articles	___	___	___
13. Writing legislative reports	___	___	___
14. Writing oversight reports	___	___	___
15. Assessing national needs	___	___	___
16. Dealing with lobbyists, interest groups	___	___	___
17. Responding to inquiries from constituents	___	___	___
18. Other (Please list or describe on back of sheet)	___	___	___

(Over, please)

BEST COPY AVAILABLE

III. WOULD ANY OF THE FOLLOWING IMPROVE THE USEFULNESS OF FUTURE OUTLOOKS FOR YOUR PURPOSES? PLEASE CHECK ALL APPLICABLE.

1. Short, 5-10 page summary ____(1)
2. Recommendations for legislative actions needed ____(2)

3. Improved presentation format (e.g., more charts, tables, graphics) ____(3)

4. Better delineation of anticipated social, economic and political impacts or problems ____(4)

5. Assignment of priorities to needs, problems, and opportunities ____(5)
6. Less scientific and technical material ____(6)

7. More specific delineation of relationships between areas, problems, and opportunities ____(7)

8. Clearer statement of changes since the last FYO ____(8)
9. Better dissemination to relevant audiences ____(9)

10. Other (Please describe.): ____(10)

IV. ARE THERE ANY OTHER COMMENTS, CRITICISMS, SUGGESTIONS, OR RECOMMENDATIONS ABOUT THE FIVE-YEAR OUTLOOKS ON SCIENCE AND TECHNOLOGY THAT YOU WOULD CARE TO MAKE?

- -

ADDITIONAL COMMENTS OR INFORMATION ON SPECIFIC QUESTIONS LISTED ABOVE

Thank you for your time and consideration.

Form Approved
OMB No. 3145-0081
Expiration Date: 6/30/84

(3) Alternate?

___1. No
___2. Yes
___3. Replacement, same position

Form # ____________ (11-14)

ID # ____________ (15-20)

Caller#____________ (21)

Original ID#:

____________ (4-9)

Date : MO: (22-23) DAY: (24-25)

State: ____________ (26-27)

OUTLOOK PROJECT TELEPHONE INTERVIEW FORM

I. Locator Data

(28) A. Obtained phone number for addressee as listed?

___1. No phone number listed for organization or addressee
___2. Phone number obtained

(29) B. Addressee at listed address and phone number?

___1. No (If No, go to Question C)
___2. Yes (If Yes, go to Question E)

(30) C. Addressee's present address and phone number available?

___1. No (If No, go to Question D)
___2. Yes (If Yes, note phone number and address, then go to Question E)

[New Number]:

[Address]:

(31) D. Does addressee have a replacement or is there a person in a comparable position?

___1. No replacement
___2. Yes (Determine who and phone number, then go to Question E)

[Name]:

[Phone Number]:

NOTE: If telephone operator or secretary asks about the nature of the business, explain that it is in connection with a study being done for the National Science Foundation on the Five-Year Outlooks on Science and Technology.
If addressee is unavailable at this time, find out when an appropriate time to call is and record it in the Telephone Call-Back Log.

II. Determination of Familiarity

E. (Mr./Mrs./Miss./Dr./Professor) ____________________, my name is ______________.
I am working with Dr. Russell Cort. We are doing a project for the National Science Foundation in connection with reports published every other year by the Foundation called the Five-Year Outlooks on Science and Technology. These reports were mandated by Congress.

We are calling a national sample of people who may have received the Five-Year Outlooks, based on mailing lists provided by the National Science Foundation.

Are you at all familiar with or aware of them?

(32)
__1. No [If No, go to Question E(3)]
__2. Yes [If person says s/he was a contributor or adviser or reviewer for any one of them, check the appropriate category(ies) in Question E(1). Otherwise, go to E(2).]

E(1). To which was respondent a contributor?

		1st FYO	2nd FYO	NAS Vol. III
(33-35)	__1. Reviewer	____ (33)	____ (34)	____ (35)
(36-38)	__2. Contributor	____ (36)	____ (37)	____ (38)
(39-41)	__3. Adviser	____ (39)	____ (40)	____ (41)

E(2). There have been two Five-Year Outlooks, the first published in the spring of 1980, the second in the spring of 1982. Are you familiar with both sets of reports?
[Describe each in more detail, with full titles. Note that the 1st FYO was 2 volumes, gray cover; the 2nd FYO was 3 volumes, blue cover.]

(42)
__1. No, only 1st FYO
__2. No, only 2nd FYO
__3. Yes
[Go to Question E(3).]

E(3). The National Academy of Sciences issued a report in the fall of 1982 called The Next Five Years, Volume III. It has also been published commercially as: Frontiers in Science and Technology: A Selected Outlook.

Are you familiar with or aware of this report or book?

(43) ___1. No [If respondent is unfamiliar with either FYOs and with Vol. III, go to Question E(4).]
___2. Yes [Go to Part III.]

E(4). Is there anyone else in your organization who you think might be familiar with the Five-Year Outlooks?

(44) ___1. No [End interview. Record in Survey Phone Log.]
___2. Yes [Obtain name and phone number. End interview. Record in Survey Log. Start new form and call.]

[Name]:

[Phone]:

III. Use of and Opinions About FYOs

I would now like to ask you a few questions about your use of (identify the appropriate reports) and your opinions about them. I would like to ask them in a fixed order and form. Your answers will be confidential unless that is not important to you. Do you want this to be confidential? _____Yes; ______No.

[If respondent is not a librarian, proceed with Question F. If respondent is a librarian, go to Question R.]

F. How familiar would you say you are with the Five-Year Outlook(s) and/or NAS Report? [Read 1,2,3 and 4 in order; circle appropriate numbers.]

	[Read---]	1. Have Read All or Parts More Than Once	2. Have Read All or Parts Once	3. Have Seen Reports, May Have Skimmed Through All or Parts	4. Can't Say for Sure
(45)	a. First FYO	1	2	3	4
(46)	b. Second FYO	1	2	3	4
(47)	c. NAS Vol.III	1	2	3	4

[Comments]:

G. Have you had occasion to use the Five-Year Outlook(s) or NAS Report for any of the following purposes? [Read list in order.]

		1st FYO	2nd FYO	NAS Vol III
(48-50)	a. Identifying Science or Technology issues, opportunities or problems	1	2	3
(51-53)	b. Proposing or preparing legislation	1	2	3
(54-56)	c. Preparing testimony for Congress or state or local legislature	1	2	3
(57-59)	d. Preparing professional books, papers or speeches	1	2	3
(60-62)	e. Preparing or recommending organization's development plans or programs	1	2	3
(63-65)	f. Preparing budgets	1	2	3
(66-68)	g. Determining policies or strategies	1	2	3
(69-71)	h. Teaching	1	2	3
(72-74)	i. Generally keeping informed on S&T developments	1	2	3

[Comments]:

H(1) Have you used the Five-Year Outlooks or NAS Vol.III for any other purpose or purposes?

(75) ___1. No [If respondent makes it clear that s/he has really not used the FYOs or NAS Vol.III, go to Question H(2), then H(3), then Question O]

___2. Yes [Please describe]

(76-79) [Description]:

(Card 2)

H(2) Is your main interest in science, technology, or S&T policy areas?

(11)
___1. Science
___2. Technology
___3. Policy
___4. Science and Technology
___5. All three areas
___6. Other (includes none of these areas)

H(3) What is the main field or topic of interest to you?

(12-13) [Describe]:

[Again: If this respondent is only vaguely familiar with FYO, has not used them, and/or says s/he has no opinion about them, go to Question Q.]

I. Compared to other reports of their kind, how useful for your purposes would you rate the Outlooks on a scale of 1-10 where 10 is the most useful? [If can't evaluate, code 20.]

(14-15) ___1. 1st FYO
(16-17) ___2. 2nd FYO
(18-19) ___3. NAS Vol.III
(20-21) ___4. FYOs generally (includes: Can't say exactly which ones.)

I(1) Are there other reports or source materials that you find more useful for the purposes you identified?

(22)
___1. No
___2. Yes [If yes: What ones come to mind?]

[List]:

[Why are they more useful?]

J. Which have you found the more useful for your purposes: the summary report (or chapter in NAS Vol.III) or the back-up source materials volume(s)?

			Summary Report	Source materials	Neither	No Opinion
(23)	a.	1st FYO	1	2	3	4
(24)	b.	2nd FYO	1	2	3	4
(25)	c.	NAS Vol.III	1	2	3	4

[Comments]:

K. Are there others in your organization (or Department) who use the Five-Year Outlooks?

(26) ___1. No
___2. Not sure
(27-28) ___3. Yes (If Yes: Could you estimate about how many? ________ (27-28))

[Comments]:

L. Some people have made suggestions for improving the Five-Year Outlooks. Do you think any of the following would be a significant improvement in future FYOs? Please answer: Definitely Yes, Perhaps, No, or No Opinion. [Read list in order.]

		Definitely	Perhaps	No	No Opinion
(29)	a. More graphs, tables, charts	1	2	3	4
(30)	b. More emphasis on social and economic costs and problems anticipated from future science or technology developments	1	2	3	4
(31)	c. Clearer statements of changes since the last *Five-Year Outlook*.	1	2	3	4
(32)	d. More emphasis on speculative or controversial forecasts.	1	2	3	4
(33)	e. Five to ten page summary of most significant trends, issues and possible problems or impacts	1	2	3	4
(34)	f. Less scientific or technical material	1	2	3	4
(35)	g. More delineation of relationships between areas, problems and developments . . .	1	2	3	4
(36)	h. More attention to international implications .	1	2	3	4
(37)	i. More attention to policy and legislative implications or actions	1	2	3	4

[Comments]:

M. Are there any other suggestions or recommendations for improvement that come to mind?

(38) ___1. No

___2. Yes (Please describe)

(39-44) [Descriptions]:

[For either No or Yes, go next to Question N]

N. What is your overall opinion about the general usefulness of the Outlooks for your purposes? [Read scale]

		[Read---]	Extremely Useful	Moderately Useful	Not very Useful	Useless	No Opinion
(45)	a.	1st FYO	1	2	3	4	5
(46)	b.	2nd FYO	1	2	3	4	5
(47)	c.	NAS Vol.III	1	2	3	4	5
(48)	d.	FYOs generally (if can't be specific)	1	2	3	4	5

[If the answer is either a 3 or a 4, ask]:

Why don't you think they are very useful?

(49-54) [Reasons]:

O. Are there any particular comments, criticisms or suggestions about the Outlooks you would care to make?

(55-60)

P. That is the end of my interview. Let me ask you again: Would you like your comments and answers to be kept confidential?

(61) ___1. No, don't care
___2. Yes

Q. For our records, may I have your title or position?

Thank you very much for your time and thoughtful assistance.

[End interview. Check off in Phone Survey Log, and in Call Back Log if appropriate.]

[Card 3]

Questions R-S: To be used with LIBRARIANS ONLY

R. Do you now have the Five-Year Outlooks (and/or NAS Vol.III or the Frontiers in Science book) on your shelves or in stock?

		No, don't have	Yes, but out on loan	Yes, on shelves now	Don't know
(11)	a. 1st FYO (Vol.I)	1	2	3	4
(12)	b. 1st FYO (Vol.II)	1	2	3	4
(13)	c. 2nd FYO	1	2	3	4
(14)	d. 2nd FYO (Vol.1)	1	2	3	4
(15)	e. 2nd FYO (Vol.2)	1	2	3	4
(16)	f. NAS Vol.III	1	2	3	4
(17)	g. Frontiers book	1	2	3	4

S. Can you estimate roughly how frequently these reports have been used?

	[Read---]	Constant Use	Frequent Use	Occasional Use	Seldom Used	Never Used	No Way to Estimate
(18)	a. 1st FYO	1	2	3	4	5	6
(19)	b. 2nd FYO	1	2	3	4	5	6
(20)	c. NAS Vol.III or Frontiers	1	2	3	4	5	6

[Comments]:

T. Can you estimate about how many different people have used these reports? [If can't estimate, code 99.]

(21-22) ___1. 1st FYO
(23-24) ___2. 2nd FYO
(25-26) ___3. MAS, Vol.III (or Frontiers)

U. Is there a particular person or persons in your organization who is or has been the main user of these reports?

(27) ___1. No
___2. Don't know, not sure
___3. Yes (Please list names and positions)

[List]:

V. Were people in your organization notified about the availability of these (this) reports?

(28) ___1. No
___2. Don't know, not sure
___3. Yes [If Yes, ask: How were people notified?]

[Description]:

W. Does your library have other reports or publications similar to the *Five-Year Outlooks in Science and Technology* in purpose or subject matter?

(29)
___1. No [Go to Question Y.]
___2. Not sure, can't say, don't know [Go to Question Y.]
___3. Yes [If Yes: What ones come to mind?]

[List]:

X. [If answer to Question W was Yes]:

Are those reports generally used more often, about the same, or less often than the *Five-Year Outlooks*?

(30)
___1. Less often
___2. About the same
___3. More often
___4. Not sure, can't say, don't know

Y. Are there any other comments you would care to make about the *Five-Year Outlooks*?

(31)
___1. No
___2. Yes

[Describe]:

Z. That is the end of my interview. Let me ask you again: Would you like your comments and answers to be kept confidential?

(32)
___1. No, don't care
___2. Yes

Thank you very much for your time and thoughtful comments.

[End interview. Check off in Phone Survey Log, and in Call Back Log if appropriate.]

APPENDIX D

Utilization Rates by Category of Respondents

Table A. Percentages of Congressional Respondents Using FYOs for Different Purposes, by Category of Respondent.

Table B. Percentages of Interviewees in Each Category that Have Used an FYO for a Particular Purpose.

Table C. Overall Percentage of Respondents Per Purpose, by Category of Interviewee.

Table A. Percentages of Congressional Respondents Using FYOs for Different Purposes, by Category of Respondent.

	Members of Congress			Legislative Assistants and Other Office Staff			Senate & House Committee Staff		
FYO	1	2	3	1	2	3	1	2	3
N 1/	5	7	7	16	18	14	24	29	24
Purposes 2/									
1	40.0	0.0	0.0	12.5	16.7	35.7	20.8	13.8	29.2
2	20.0	14.3	0.0	28.6	16.7	28.6	20.8	17.2	25.0
3	20.0	28.6	57.1	31.3	37.5	57.1	55.2	44.8	62.5
4	0.0	14.3	28.6	12.5	5.6	7.1	29.2	24.1	33.3
5	20.0	57.1	57.1	18.8	22.2	42.9	41.7	27.6	41.7
6	60.0	42.9	28.6	25.0	33.3	50.0	62.5	51.7	70.8
7	20.0	14.3	14.3	18.8	16.7	21.4	54.2	48.3	66.7
8	40.0	14.3	28.6	18.8	11.1	28.6	29.2	27.6	37.5
9	20.0	14.3	28.6	18.8	16.7	21.4	41.7	37.9	50.0
10	0.0	28.6	28.6	31.3	16.7	35.7	37.5	31.0	50.0
11	20.0	14.3	28.6	37.5	27.8	57.1	41.7	31.0	45.8
12	0.0	42.9	28.6	43.8	27.8	57.1	54.2	41.4	62.5
13	0.0	28.6	14.3	18.8	11.1	14.3	33.3	31.0	37.5
14	0.0	14.3	28.6	25.0	11.1	14.3	29.2	27.6	37.5
15	60.0	28.6	42.9	37.5	27.8	50.0	54.2	41.4	62.5
16	40.0	28.6	57.1	18.8	16.7	35.7	25.0	24.1	29.2
17	20.0	28.6	71.4	25.0	16.7	28.6	25.0	31.0	54.2
Overall average Per Item...	22.4	24.4	31.9	23.5	19.0	34.5	39.5	32.3	46.6

1/ N is the number of persons in a given category who were familiar with a particular FYO. Percentages in each ~~row~~ column are based on the N for the ~~row~~ column.

2/ Purposes numbered in this table in the order in which they occurred on the questionnaire (see listing on the next page).

Table A (Cont'd)

Listing of Purposes

1. Proposing legislation
2. Drafting legislation or amendments
3. Preparing hearing background papers

4. Identifying potential witnesses
5. Evaluating budget requests
6. Identifying S&T related issues for legislative agendas

7. Identifying S&T related issues for oversight agendas
8. Determining legislative priorities
9. Determining oversight priorities

10. Doing foresight or futures research activities
11. Preparing floor remarks
12. Writing speeches, articles

13. Writing legislative reports
14. Writing oversight reports
15. Assessing national needs

16. Dealing with lobbyists, interest groups
17. Responding to inquiries from constituents

Table 8. Percentages of Interviewees in Each Category that Have Used an FYO for a Particular Purpose.

CATEGORY OF RESPONDENTS	FYO	N [2]	PURPOSES [1] 1	2	3	4	5	6	7	8	9
1. Federal Government	1	18	55.6%	16.7%	33.3%	50.0%	38.9%	16.7%	44.4%	16.7%	94.4%
	2	19	57.9	15.8	26.3	47.4	52.6	15.8	47.4	10.5	94.7
	3	10	40.0	20.0	20.0	20.0	50.0	10.0	40.0	0.0	70.0
2. NSF Officials	1	20	35.0	5.0	20.0	45.0	35.0	30.0	50.0	0.0	85.0
	2	19	31.6	5.3	15.8	36.8	21.1	21.1	42.1	0.0	73.7
	3	13	15.4	0.0	0.0	15.4	15.4	7.7	23.1	0.0	53.8
3. Former NSB Members	1	6	100.0	16.7	16.7	83.3	33.3	33.3	50.0	16.7	100.0
	2	10	70.0	10.0	30.0	60.0	30.0	20.0	40.0	20.0	90.0
	3	6	100.0	0.0	0.0	83.3	33.3	33.3	50.0	16.7	100.0
4. Current NSB Members	1	5	60.0	20.0	20.0	40.0	0.0	0.0	60.0	20.0	80.0
	2	4	50.0	25.0	25.0	25.0	0.0	0.0	50.0	0.0	75.0
	3	2	50.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	100.0
5. S & T Societies	1	9	55.6	22.2	33.3	55.6	44.4	11.1	44.4	44.4	88.9
	2	15	53.3	13.3	20.0	40.0	33.3	20.0	40.0	33.3	93.3
	3	3	0.0	0.0	0.0	33.3	0.0	33.3	33.3	33.3	100.0
6. Research Administrators	1	29	65.5	13.8	27.6	44.8	62.1	34.5	69.0	13.8	93.1
	2	33	72.7	6.1	27.3	51.5	66.7	45.5	69.7	12.1	97.0
	3	8	75.0	25.0	37.5	50.0	75.0	37.5	75.0	12.5	87.5
7. SRS/R&D Funds Report	1	12	58.3	0.0	0.0	41.7	25.0	8.3	25.0	0.0	50.0
	2	12	66.7	8.3	8.3	66.7	33.3	16.7	33.3	8.3	66.7
	3	9	44.4	0.0	0.0	33.3	33.3	0.0	22.2	0.0	33.3
8. Governors' Science Advisors	1	1	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0	100.0
	2	3	66.7	0.0	66.7	0.0	100.0	66.7	66.7	33.3	100.0
	3	2	50.0	0.0	50.0	0.0	50.0	50.0	50.0	0.0	50.0
9. Pres.-State Academy of Science	None of the five persons called was aware of any FYO										
10. NSF Advisory Committees	1	31	32.3	0.0	6.5	41.9	32.3	5.5	41.9	25.8	90.3
	2	30	40.0	3.3	6.7	43.3	30.0	10.0	50.0	30.0	93.3
	3	13	38.5	0.0	7.7	46.2	23.1	0.0	30.8	38.5	69.2
11. General Lists, U.S. Requestors	1	9	55.6	0.0	22.2	44.4	55.6	0.0	22.2	33.3	88.9
	2	5	80.0	0.0	40.0	40.0	40.0	0.0	20.0	60.0	80.0
	3	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12. Embassies (Mostly U.S. Overseas)	1	2	0.0	0.0	0.0	50.0	0.0	0.0	0.0	50.0	50.0
	2	4	25.0	0.0	0.0	25.0	0.0	0.0	0.0	25.0	75.0
	3	3	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	33.3

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[1] Purposes are numbered in this table in the order in which they occurred in the interview (*see* attached listing on the following page).

[2] The N for each category and FYO is the number of people in the category who were familiar with the particular FYO. Percentages in a given row are based on the N for the row.

Table B (Continued...)

Listing of Purposes

1. Identifying S or T issues, opportunities or problems.
2. Proposing or preparing legislation.
3. Preparing testimony for Congress or state or local legislature.
4. Preparing professional books, papers or speeches.
5. Preparing or recommending organization's development plans or programs.
6. Preparing budgets.
7. Determining policies or strategies.
8. Teaching.
9. Generally keeping informed on S & T developments.

Table C. Overall Percentage of Respondents Per Purpose, by Category of Interviewee. 1/

	FYO-1		FYO-2		FYO-3	
	%	N 2/	%	N 2/	%	N 2/
1. Federal Government	40.7	16	40.9	19	31.1	10
2. NSF Officials	34.4	20	27.5	19	16.2	13
3. Former NSB Members	51.9	6	41.1	10	46.3	6
4. Current NSB Members	33.3	5	27.8	4	22.2	2
5. S & T Societies	44.4	9	38.5	15	25.9	3
6. Research Administrators	47.1	29	49.9	33	52.8	8
7. SRS/R&D Funds Report	23.1	12	34.3	12	18.5	9
8. Governors' Science Advisors	33.3	1	55.6	3	33.3	[illegible]
9. Pres.-State Academy of Science	-		-		-	
10. NSF Advisory Committees	30.8	31	34.1	30	28.2	13
11. General Lists, U.S. Requestors	35.8	9	40.0	5	0.0	1
12. Embassies (Mostly U.S. Overseas)	16.7	2	16.7	4	7.4	3

1/ The percentage in each cell was obtained, as in other tables, by dividing the total number of persons indicating any of the 9 purposes by 9xN. Thus, the utilization rates shown here are the averages of the percentages of use in each row of Table B.

2/ N is the total number of people who were familiar with the indicated FYO.